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Demonstration of Sewer Relining by the Insituform Process, Northbrook, Illinois

Driver, Olson-Degraff and Associates
Rockford, IL

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This study was initiated with the overall objective of determining the effectiveness of a new process of lining sewers called Insituform.

Two test sections of sewer in need of rehabilitation were lined to evaluate both the effectiveness of the liner in eliminating infiltration and the liner's effect on the flow characteristics of the sewer. Physical characteristics of the installed liner were tested by running destructive tests on specimens.

The conclusions, recommendations and installation procedures described in the text in this report should be of help to potential users in determining the viability of this rehabilitation technique as it may apply to their needs. This study documents the fact that the Insituform method of lining deteriorated sewers is an effective process for eliminating infiltration from lines, as well as improving the hydraulics and structural integrity of damaged conduits. The economical advantages of this system are mainly dependent upon physical conditions of each application.

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DEMONSTRATION OF SEWER RELINING BY THE INSITUFORM PROCESS, NORTHBROOK, IL.

by

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Grant No. R-806322

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This study was conducted
in cooperation with
Public Works Department
Village of Northbrook, Illinois 60062

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DISCLAIMER

Although the information described in this article has been funded wholly or in part by the United States Environmental Protection Agency through assistance agreement number R-806322 to Driver, Olson-Degraff & Associates, it has not been subjected to the Agency's required peer and administrative review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The work described herein was undertaken to evaluate Insituform a method of lining sewers in need of rehabilitation. Based on an evaluation of the results of the study using the Insituform method of lining, this method has proved to be a viable alternative to present conventional sewer lining methods.

Francis T. Mayo
Director
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PREFACE

The requirement by the E P A for sewer system evaluation surveys has shown that in many cases the most cost effective approach to pollution abatement is through sewer collection system rehabilitation. The increased activity in sewer collection system rehabilitation brought about by the funding of this work under various State and Federal grant programs has necessitated the search for improved procedures. These improvements may be in the form of advances in techniques of existing rehabilitation procedures and/or in the development of new rehabilitation procedures.

In 1971 Insituform a state-of-the-art method of sewer and pipeline rehabilitation was developed in Great Britain. After four years of testing the first licenses were granted to British contractors. This was followed in 1976 by the granting of licenses to European and Australian contractors. In 1977 Insituform came to North America.

The interest in Insituform as a rehabilitation procedure was almost immediate and spread quickly throughout North America. The only problem seemed to be the lack of data as related to North American standards for work to be performed through public agencies.

The object then of this study was to establish the feasibility and effectiveness of Insituform lining of sewers in need of rehabilitation. The process consists of inserting a flexible felt bag treated with a thermo setting resin into a sewer by means of a static water head. Hot water is then circulated in the line, thus curing the liner. The procedure in most cases requires no excavation which is of great advantage in densely built-up areas.

In order to obtain data two sections of Insituform were installed in a controlled test sewer line which was in need of rehabilitation.

The ease of installation along with flow characteristics and infiltration of the sections before and after lining were documented. Characteristics of the final product were determined by removing in-place sections and specimens made from job site materials to run destructive tests. Tests were performed in an approved laboratory. The cost of this method of sewer lining was analyzed in comparison to alternatives.

The study was limited to Insituform and did not compare it with other methods of rehabilitation except in the area of cost and ease of installation.

ABSTRACT

This research was initiated with the overall objective of determining the effectivenes of a new process of lining sewers called Insituform.

Two test sections of sewer in need of rehabilitation were lined to evaluate both the effectiveness of the liner in eliminating infiltration and the liner's effect on the flow characteristics of the sewer. Physical characteristics of the installed liner were tested by running destructive tests on specimens made from job site materials.

Results of the liner installation were evaluated in terms of effectiveness in elimination of infiltration and change in flow characteristics, i.e. infiltration and flow studies performed before and after lining. Destructive test results were evaluated in terms of the physical characteristics of the liner material, i.e. tensile properties, shear strength, etc.

This study is the first of two studies being performed on Insituform. This study was limited to Insituform and did not compare it with other methods of rehabilitation except in the area of cost and ease of installation.

The conclusions, recommendations and installation procedures described in the text in this report should be of help to potential users in determining the viability of this rehabilitation technique as it may apply to their needs. This study documents the fact that the Insituform method of lining deteriorated sewers is an effective process for eliminating infiltration from lines, as well as improving the hydraulics and structural integrity of damaged conduits. The economical advantages of this system are mainly dependent upon physical conditions of each application.

This report was submitted in fulfillment of Grant R-806322 by Driver, Olson and DeGraff, Consulting Engineers under sponsorship of the U.S. Environmental Protection Agency and the Village of Northbrook, Illinois.

This report covers the period May 7, 1979 to September 30, 1980 and work was completed as of March 15, 1981.

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The consultant expresses its thanks to the members of the technical advisory committee.

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LIST OF ABBREVIATIONS AND SYMBOLS

G	— gallons
GPM	-- gallons per minute
GPD	-- gallons per day
MGD	-- million gallons per day
m or M	-- meters
cm	-- centimeters
mm	-- millimeters
l	-- liters
M^3	-- cubic meters
M^3/min.	-- cubic meters per minute
M^3/D	-- cubic meters per day
ft	-- feet
in.	-- inches
ft^3(C.F.)	-- cubic feet
min. (m)	-- minutes
sec. (s)	-- seconds
L.F.	-- lineal feet
g	-- grams
kg	-- kilograms
°F	-- degrees Fahrenheit
°C	-- degrees Centigrade

SECTION 1

INTRODUCTION

The information contained in this report is the joint effort of the Village of Northbrook, Illinois, U.S. Environmental Protection Agency, Insituform (Pipe and Structures) Limited, Northampton England, Insituform East, Inc., Hyattsville, Maryland and Driver, Olson and DeGraff, Consulting Engineers, Rockford, Illinois. Insituform Limited and Insituform East participation in this study was limited to that of material supplier and installer respectively.

This research program was initiated with the overall objective of determining feasibility and effectiveness of the Insituform method of lining sewers in need of rehabilitation.

Two controlled test sections, which required rehabilitation, were lined with Insituform. Observations and documentation were made of the ease of installation, as well as flow characteristics and infiltration of each section before and after lining. Characteristics of the final product were determined by performing destructive tests on in-place sections as well as prepared specimens.

The description of the equipment used in the installation as well as the description of the installation procedures, are meant to familiarize potential users as to the adaptability of the process to their needs.

Flow characteristics, infiltration data before and after lining, as well as physical properties of the material, are meant to help municipalities, sanitary districts and design engineers faced with upcoming rehabilitation projects determine the feasibility of this process for their application. Flow characteristics, infiltration elimination data and cost of installation considerations are discussed in this report in an effort to help these entities in making cost-effective rehabilitation judgements.

The material properties presented herein are a result of destructive tests made by an independent laboratory on representative test specimens, and should be considered along with published information in designing each project.

SECTION 2

CONCLUSIONS

The lining of sewers in need of rehabilitation by the Insituform process is an effective technique for eliminating infiltration and prolonging the life expectancy of a sewer. The finished product, in fact, will have greater structural integrity and may also have greater flow-carrying capacity than the original sewer at the time of installation. The fact that the in-place (in situ) liner is void of joints between manhole structures eliminates the expectance of future infiltration or root intrusion over the life of the liner materials.

This study has shown Insituform to be a viable alternative to other more conventional sewer rehabilitation methods.

The cost-effectiveness of the Insituform product, as well as other methods of rehabilitation, must be evaluated on an individual basis. The results of this analysis indicate Insituform to be most cost-effective in the following applications of conduit rehabilitation:

1. Locations where construction is very costly due to high restoration cost of disturbed areas.

2. Areas where excavating is costly due to a high water table, unfavorable soil conditions or extreme depth.

3. Sections in which anticipated future flow does not exceed capacity.

4. Areas where sewers are not readily accessible between manholes, or other points of access.

5. Instances in which rehabilitation time is limited due to bypassing requirements, and/or loss of commerce due to disruption of surface facilities.

6. Locations where existing sewers are in such a deteriorated condition as to render other methods of rehabilitation impractical or impossible.

7. Areas where resistivity to chemically reactive types of waste is required.

8. Sites in which the conduit cross-section is irregular in shape and size, where conventional rehabilitation process will not serve

the purpose.

Insituform is not the answer to all sewer line rehabilitation problems, but the findings of this study certainly have to classify it as a state-of-the-art technique available as an alternative to serve the rehabilitation program.

Some potential disadvantages of the Insituform Process are as follows:

1. Additional cost is incurred due to the need for a thorough interior inspection by remote camera immediately prior to repair of that area of the pipeline.
2. A degree of expertise is required of the installer to assure that the resins are of suitable quality, properly mixed and cured and heated to the correct temperature.
3. The chemically treated bag, if improperly installed, may totally block the pipeline to be repaired and require excavation to gain access to it. A fresh lining bag would then be needed.
4. In certain types of installations, where there are lateral connections to the pipe that is being lined, it is necessary to curtail water service until the lining has been completed.
5. There is presently a lack of trained personnel competent to utilize the process and perform the installations.

This study was limited to the Insituform rehabilitation technique. Comparison to alternative lining methods included evaluation on installation and fabrication limitations associated with: (1) cold weather; (2) length of section; (3) access point; (4) root problems; and (5) safety hazards and procedures.

1. Cold weather limitations for Insituform and alternative lining methods are similar regarding the effects upon manpower and equipment. Cold weather problems associated with added heat required in the curing of the Insituform liner are less significant in the overall process when balanced against excavation and material handling required with other techniques, as evidenced by the lack of lining activities in northern states during severe weather.
2. Historically, polyethylene slip-lining techniques have had the capability of longer single runs. However, in most cases the practical single-length sections are less than the physically capable lengths due to associated conditions within the actual sewer line.
3. The Insituform technique requires less area on-site than alternatives in order to stage the lining operation. The curing equipment can be remotely-located, but there are practical limitations. Inversion equipment and

materials may be transported manually to the site from a remote location. Restoration is normally minimal and can be performed by hand. Slip-lining can be fused remotely and can be installed remotely with very distinct limitations. Excavation equipment is required on site for staging pits and service reinstatement; surface restoration may be considerable.

4. Tree root removal is a preferable preliminary step in all types of sewer lining processes. The presence of roots in Insituform and slip-lining can act to distort the cross-sectional shape of the liner. The degree of distortion, depending upon the root mass, may cause unnecessary strains to result in the liner.

5. All lining techniques require a common sense approach to safety which is consistent with their respective operations and both material suppliers and manufacturers recommendations.

SECTION 3

RECOMMENDATIONS

The information gained during this study has answered many questions with regard to the use of Insituform in sewer system rehabilitation programs. This review has also shown the need for additional, more detailed analysis beyond the scope of this report. A study should be undertaken to examine the relative success or failure of existing Insituform installations nationwide, to develop a general assessment of this innovative rehabilitation technique. Head to head comparisons with other rehabilitation methods, considering costs, results and environmental impact should be studied as a minimum.

The development of standard specifications for Insituform lining, or a guideline for the preparation of said specification should be undertaken, with cooperation between material suppliers, installers, engineers, and public agencies. As a part of the guidelines for these specifications, design concepts should be made available to prospective users. Many potential users of Insituform lining are reluctant to consider the product because of the limited historical data available on United States installations.

Additionally, the flow carrying characteristics should be studied in more detail so that the flow carrying characteristics of the finished product can be accurately predicted.

Safety standards related to all phases of the installation procedures should be developed. Insituform installation procedures as with other sewer rehabilitation techniques require working under many adverse conditions such as: nighttime operations, areas not readily accessible, undesirable climate, and all other hazards associated with underground construction, i.e. caving, and damage to existing utilities.

Observations made during the Northbrook installation indicated that surplus resin penetrated existing joint material. The stabilizing effect of this resin on porous joint material should be determined by appropriate laboratory testing.

Insituform and other rehabilitation techniques presently in use are limited, in most cases to mainline sewers. There is growing evidence, substantiated by the fact projects in many cases have not achieved their predicted infiltration and inflow (I/I) reductions, that rehabilitation of mainline sewers is causing a migration of the I/I problem to the house lateral, or that a significant portion of the problem in fact emanates from the lateral. Other causes of I/I overestimates could also be attributable to ground water level changes, faulty estimates of the effectiveness of the rehabilitation project, or infiltration migration.

Rehabilitation of house or service connections has some problems not present in mainline sewer rehabilitation in that they are in most cases accessible at only one end, are of small diameter, and require working and excavating on private property.

A study of house or service connection rehabilitation by Insituform should be undertaken to determine if it can become a cost-effective solution.

SECTION 4

DEMONSTRATION OF SEWER RELINING
BY THE
INSITUFORM PROCESS, NORTHBROOK, IL.

NEED FOR THE NORTHBROOK SEWER RELINING STUDY

Many communities and sanitary districts throughout the nation are finding it exceedingly difficult to meet new, more stringent stream quality criteria, to maintain existing facilities, and to satisfactorily service new and existing customers with present revenues.

If this shortfall of required funds continues, it may pose a public health hazard to present and future generations. Only through a series of carefully administered cost-effective programs can we expect to assure the safety of our future environment. In short we must get the maximum benefit out of each dollar invested.

Sewer system evaluation surveys have in many cases shown it to be more cost-effective to remove from sanitary collection systems extraneous water sources than to transport and provide treatment for this infiltration and/or inflow. Removal of clear water from the sewers in most cases is accomplished by rehabilitation of various components of the wastewater transportation network.

The rehabilitation of sewer collection systems may include one or all of the following techniques:

1. Grouting of deteriorating or leaking pipe joints.
2. Pressure grouting of manhole leaks.
3. Point replacement of cracked or structurally-failed sections of pipe.
4. Total line replacement.
5. Manhole rehabilitation by repairing and sealing.
6. Manhole replacement.
7. Sewer lining (slip-lining, Centri-line method, Insituforming).

8. Replacement sewer construction.

9. Disconnection of illegal connections.

10. Control of root intrusion.

No one technique is best suited for all situations and circumstances. In order to select the technique best suited to a specific need the advantages and disadvantages of each must be carefully considered taking into account their respective benefits and costs.

Grouting

Grouting is the placement of acrylonitrile gel, urethane foam, hydraulic cement, or other acceptable material on, in, or outside of a sewer pipe joint for the purpose of preventing exfiltration, infiltration, and the intrusion of soil or roots through defective joints.

Grouting techniques generally offer the following advantages relative to other methods:

1. Most leaks in pipe joints can be sealed by one of the above mentioned grouting methods.

2. Many of the materials used in grouting are flexible, and therefore some movement of sealed joints can be accommodated without destroying the integrity of the seal.

3. Some grouting materials create impervious masses outside the joint by saturating and stabilizing the backfill, and therefore continued movement of improperly supported pipe may be arrested.

There are, however, certain limitations and disadvantages of the grouting technique:

1. Some grouting materials show signs of deterioration and shrinkage after repeated periods of wet/dry cycles, rendering the joint susceptible to infiltration.

2. Continued movement of pipe beyond flexibility limits of the grout material may cause seal failure.

3. Grout material adds little or no structural strength to the pipe joint.

Pressure Grouting of Manholes

Pressure grouting of a manhole is effective when the area of infiltration entry is small and well defined. Pressure grouting is a quick and economical method of eliminating infiltration because all work can be done at one time with a single crew and setup. Pressure grouting should not be used where infiltration entry is not well defined or where the sealing of one entry point would merely divert the infiltration to another point.

Point Replacement

Point replacement of cracked or structurally failed sections of pipe is the actual excavation, removal, and replacement of a limited number of pipe sections within a given stretch of line between two manholes. Point replacement in most cases is limited to a nominal length of sewer pipe, which generally is some multiple of the length of a single section of pipe.

In many cases a given length of sewer between two manholes is in good condition except for one or two pipe sections that have failed. In this case the most cost-effective rehabilitation method is to locate and repair only the deteriorated sections. The repairing of only the defective section not only reduces the rehabilitation cost, but also can be done with the least possible disruption to surface conditions, and in many cases requires no bypass pumping or interruption in service. Point replacement does, however, require accurate location of defective sections by internal inspection prior to any excavation, and normally has a high cost per unit length restoration.

It is also very important when doing point replacement to extend the work to a length that insures that the entire failed stretch of pipe is replaced. Point replacement must also correct the cause of the failure. Many times existing bedding must be stabilized, and well-compacted, granular backfill installed.

Total Replacement

If there are a number of point replacements in a given stretch of sewer line it may be more cost-effective to perform total replacement between manholes. Total replacement is the excavation of an entire stretch of sewer line extending between one or several pairs of manholes.

Provided the design and installation techniques used for repair are proper, the total replacement of a line provides the opportunity to correct the reason for the original failure and assures the total rehabilitation of the line.

The cost of this method of rehabilitation may far exceed that for normal new construction because the area probably has become built-up over time, thus necessitating immense restoration costs; also, service connections must be handled live, and upstream sewage must be bypassed.

Manhole Rehabilitation by Repairing and Sealing

Manhole rehabilitation by repairing and sealing may consist of one or more of the following structural repairs: (1) manhole rim and lid adjustment or replacement; (2) step replacement; (3) invert and bench repair; and (4) repair and sealing of manhole walls.

Rehabilitation of existing manholes is relatively inexpensive, creates minimal disruption within the environment, and can usually be done by a small local contractor or municipal forces. This alternative of infiltration control can be very effective in eliminating significant amounts of clear water at low unit costs. Normally all work can be done without sewer flow interruption.

Manholes if properly rehabilitated should be expected to have a useful life similar to the sewer system. Manholes in heavy traffic areas may need continual maintenance due to vibrations caused by the traffic. Minor manhole rehabilitation is a means of buying time until total replacement of the unit is necessary.

Manhole Replacement

Manhole replacement is the removal of an existing structure and replacing it with a complete new unit. This permits the contractor to correct or allow for the factors which initially contributed to the manhole failure. New materials and construction methods should result in a better, longer-life manhole than the original unit was when it was first installed.

Sewer Lining

Sewer lining by slip-lining, Centri-line method, or Insituforming is the placement, by some means, of a new material within an existing deteriorated sewer. When completed, the technique causes the existing conduit to have a complete new internal surface, with much different flow properties due to changes in the pipe-roughness and hydraulic cross-section. The disruption to the surrounding surface is inherently minimal in this operation; cost is less than that associated with replacement. The new line normally is much smoother and is impervious to root growth, which assures future integrity of the sector. However, the problem remains that excavations must be made at each service connection for the purpose of making reconnection, except in the case of Insituform where the service connection is renewed by a remotely controlled cutter.

Sewer lining may not be used in pipe where sections have protruding service taps or are collapsed to the point that the lining material is prohibited from passing until point repair is performed. Reduction to inside diameter of the lined pipe may reduce the capacity of the pipe depending upon reduction and the improvement in the smoothness of the conduit. Sewer lining is a very specialized field, and therefore contractors and competition may be somewhat limited in some geographic areas.

Insituform, a relatively new method of sewer lining in the United States, appears to be a "state-of-the-art" improvement in sewer rehabilitation. It is felt by some that current methods of lining sewer, while effective in eliminating infiltration, are not satisfactory for other reasons, such as reduction in hydraulic capacity as well as the inconvenience associated with slip-lining. Staging requirements for slip-lining necessitates excavation for both liner insertion and service reinstatement. Inaccessible areas or areas where restoration costs are prohibitive are not suitable for slip-lining. Small diameter pipe size limitations for the Centri-line method restrict the satisfactory use of this current lining method. Insituform has the major advantage of generally requiring no excavation and therefore, very little restoration in the installation process, even in the course of reinstating lateral connections. In densely populated areas, under permanent structures, on the backs of property lines, or in roadways where surface restoration costs or techniques are prohibitive it would seem that a cost convenience savings could be realized over the conventional slip-lining procedure, while at the same time creating negligible disturbance to traffic, working environments, and existing surface features. Conventional pipe lining methods are economically advantageous in lines where carrying capacity is not critical and where there are not a significant amount of taps.

There are several reasons to feel that this system of relining sewers deserves further attention. As previously stated, due to the fact that Insituform lining typically requires no excavation, it appears to be generally competitive in overall cost with standard polyethylene liner installations, especially in built up areas where there are numerous service taps. Further in line with this "no-excavation" concept, inconveniences due to traffic control and rear-yard excavation can be virtually eliminated. This process, in effect, creates a new pipe within the existing one; thereby, lending a degree of structural integrity to the outside conduit.

Since the material installed in the lining work is very thin (1/8 in.[3 mm]--3/4 in.[18 mm]) and molds itself under a static hydraulic head against the walls of the existing sewer, there is virtually no reduction in line size. This fact, coupled with the increased liner smoothness, may result in an increase in the capacity of a section. The absence of an annular space between the existing pipe and the liner precludes any infiltration from being conducted along the space to the downstream manhole. This occurrence is quite prevalent with a polyethylene liner installation. For a typical section of 12 in. (30 cm) diameter sewer, a 10.75 in. (27.3 cm) O.D. polyethylene liner would be used, thus creating an annular space of .625 in. (1.6 cm) between the liner and sewer; this, coupled with an approximate wall thickness of 0.4 in. (1.0 cm) significantly reduces the cross-sectional area of the conduit. As mentioned in other sections of this report, ground water may migrate along paths of reduced flow resistance (trenches, etc.), manifesting itself in the form of infiltration in downstream manholes and service lines. Therefore, manholes and services should be rehabilitated as part of a total project.

Present Insituform installations in the United States range in size from 4 in. (10 cm) through 36 in. (92 cm) and vary in lengths from 80 ft (24 m) to 500 ft (150 m) for a single inversion. Size limitations are those imposed by economics and physical material properties and handling requirements. Smaller diameter inversions require greater inversion heads of pressurized inversion while progressively larger diameters require greater boiler/heating capacities and larger diameter inversions also require mechanical assistance in handling the bag because of the weight of the bag and resin. Restrictions caused by manhole rings can be a problem in inversions for sewers greater than 18 in. (46 cm) in diameter because of the necessity of getting a rigid inversion elbow down into the manhole. This problem can be surmounted by removing the ring and upper section of the manhole or by using top inversion procedures which do not require an inversion elbow.

Insituform can be custom-designed for each application. The dimensions of the "bag" can be designed per section; the lining can conform to any type of configuration, whereas polyethylene liners are generally restricted to circular cross-sections. The heat sensitive polyester resin, which in the Insituform method is impregnated into the felt bag, can also be custom designed to resist a wide range of chemical environments.

One of the chief disadvantages of the Insituform process is the limited number of licensed installers in the United States. Although the European-born process has been in the United States well over three years at present there are only three installers currently licensed by the parent firm, Insituform International. There has been some talk by Insituform International that a nationwide licensing program is to be forthcoming in the very near future. At present, however, Insituform installation is limited to selected areas served by the three installers, consequently the vast majority of installations are in the central, eastern seaboard states.

The physical properties of Insituform as installed have not been well documented in this nation, and with the lack of a long history of successful installations many public agencies and potential users have been reluctant to consider its use.

Another disadvantage presently associated with this technique is that there are no standard specifications for product installation and materials. This makes it quite difficult for engineers to either specify Insituform or inspect the job performance with adequate assurances.

SITE SELECTION FOR SEWER LINING STUDY BY INSITUFORM PROCESS

The selection of a site for this project was based upon finding a community located in a densely populated area where rehabilitation requirements had been demonstrated by means of an approved Sewer System Evaluation Survey to be cost-effective. The community also had to be willing to commit capital and manpower in order to sponsor the program.

Northbrook, Illinois, which is a suburb located northwest of Chicago, agreed to pursue this endeavor by applying for Federal participation regarding the study funds.

This community, along with fitting the above description, has been actively engaged in bringing their sewer system into compliance with State, Federal and local discharge requirements.

Northbrook next met with their Engineer to select a section of sewer, which had been previously determined by the Village Sewer System Evaluation Survey to have excess infiltration, such that the rehabilitation of said section would be cost-effective through a relining procedure. The two most important criteria used for selecting the study section was that it be in an area which normally experiences extended periods of high ground water, and that the actual conduit is deteriorated to the extent that clear water may freely enter.

Typical physical conditions of the sewer pipe in the test section were offset joints, leaking joints, sags, radial cracks, lateral cracks, and multiple cracks. The study section was selected such that flow and infiltration quantities would be accurately monitored and documented both before and after the liner was installed. Special consideration was given to accessibility of the site for the purposes of installation and observation by interested parties during the inversion operation. This last requirement precludes any site selection on private property and/or rear-yard easements.

After reviewing several sites, the final selection was made to use a 585 ft (175 m) section of 12 in. (30 cm) diameter sanitary sewer depicted in Figure 1, located on Skokie Highway, on the easterly boundary of Northbrook. The line rehabilitated is located midway between the edge of pavement and the west property line in a grass swale.

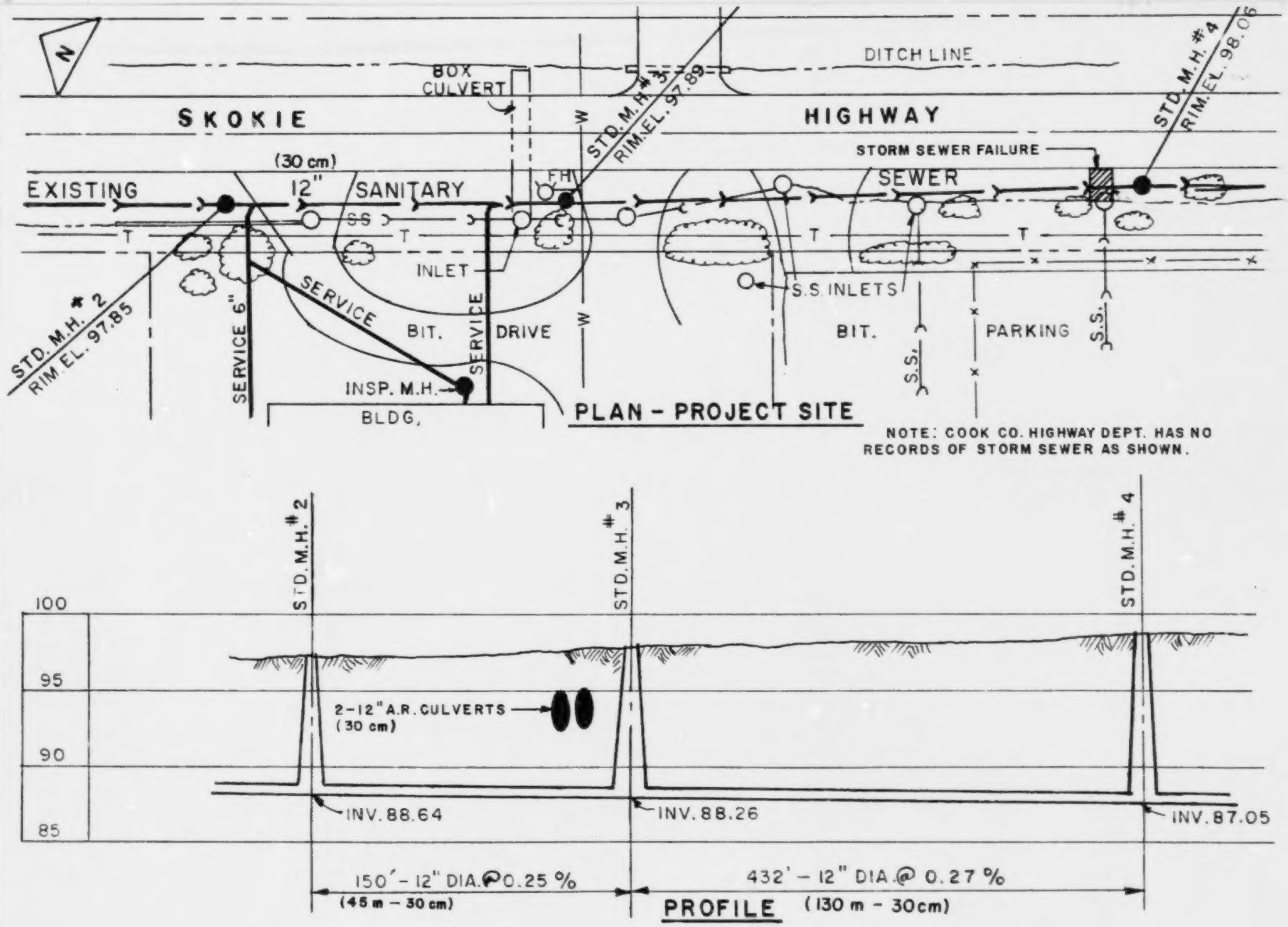
N
DITCH LINE
BOX CULVERT
SKOKIE
HIGHWAY
STD. M.H. # 3
RIM. EL. 97.89
STD. M.H. #4
RIM. EL. 98.06
STORM SEWER FAILURE
(30 cm)
EXISTING
12"
SANITARY
SEWER
F.H.
SS
T
W
INLET
SERVICE
BIT.
DRIVE
S.S. INLETS
PARKING
S.S.
STD. M.H. # 2
RIM. EL. 97.85
SERVICE 6"
INSP. M.H.
BLDG.
PLAN - PROJECT SITE
NOTE: COOK CO. HIGHWAY DEPT. HAS NO RECORDS OF STORM SEWER AS SHOWN.
STD. M.H. # 2
STD. M.H. # 3
STD. M.H. # 4
100
95
90
85
2-12" A.R. CULVERTS (30 cm)
INV. 88.64
INV. 88.26
INV. 87.05
150' - 12" DIA. @ 0.25 %
(45 m - 30 cm)
432' - 12" DIA. @ 0.27 %
(130 m - 30cm)
PROFILE

Figure 1. Test section for sewer relining by Insituform process.

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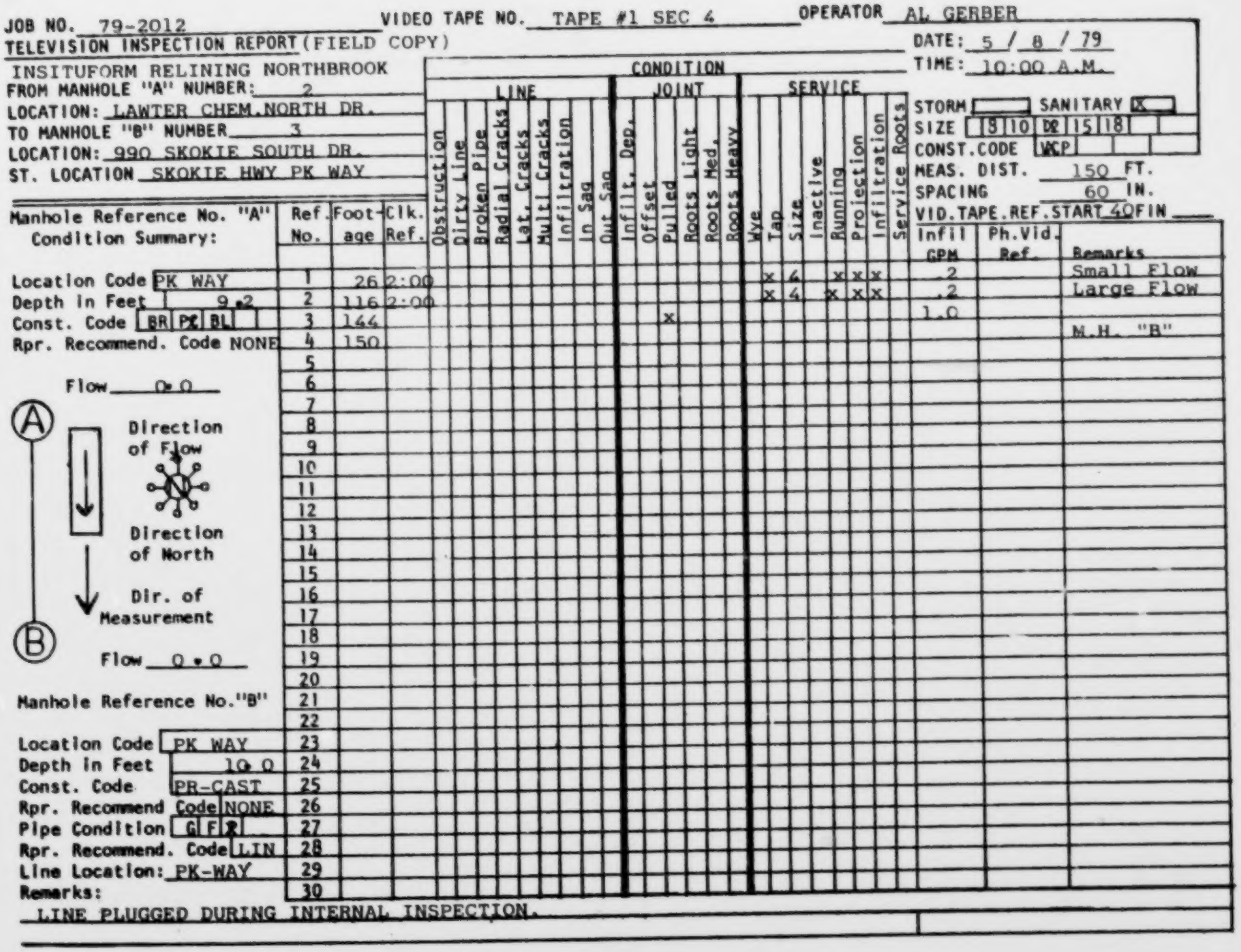
CONDITIONS OF SANITARY SEWER TO BE LINED

Historical data from the Village of Northbrook records indicated this 12 in. (30 cm) sanitary sewer was installed in 1962 by a private contractor. The Village policy regarding Public Works projects at that time did not require full time inspection by Village forces during construction. Interviews with municipal employees of the period, along with the exposure of services for the Insituform installation, has given a good idea of construction conditions encountered by the original contractor. The area then, as it is today, was subject to extended periods of high water table. The sewer was constructed directly under a marginally sloped roadside ditch in which standing water is common. Average water table is consistently 6 in. (15 cm) above the top of the sanitary sewer pipe. Unfortunately during the testing period the ground water table was relatively low. In addition to the high water table, the soil conditions in this location vary widely from clay to silty loam, with clay the predominant layer providing bedding for the sewer. This soil condition along with the high water table would tend to make proper trench bottom conditions difficult without improved bedding. Available records and site evidence do not indicate that improved bedding was called for or used during the laying of this sewer.

The present area served by the two test sections consists of both residential and commercial users. Typically the sewer flow ranges from 360 GPM ($1.4M^3$/min) to 580 GPM ($2.2M^3$/min), but Village employees have witnessed considerable surcharging events through this stretch in the recent past, closely following precipitation.

Prior to making the internal inspection of the sewer, preparatory cleaning was performed by the Village of Northbrook Public Works Department forces using a high pressure water jet. The materials cleaned from each section were trapped at the downstream manhole and removed. Investigation of the material removed from the conduit showed the presence of clay tile fragments from upstream breakages and granular material which may have been roadway debris or some sewer backfill material.

After the sewer was cleaned sufficiently to allow a representative picture, each section was inspected by means of closed-circuit television system. Internal inspection revealed that the pipe in the test section had many offset and pulled joints which were sources of visible infiltration, as well as radial and longitudinal cracks in many locations. Some sections of conduit were cracked to the extent that they were rendered structurally unstable. When the internal inspection video-tapes were compared with the earlier tapes of the sewer, which were made some three years earlier during the Sewer System Evaluation Survey, it was realized that conditions had significantly worsened during the intervening period. The condition of the sewer had deteriorated to the extent that there were sections that were no longer circular. Copies of the TV logs are included in Figures 2 and 3. The theoretical capacity of the existing 12 in. (30 cm) diameter vitrified clay pipe, which has a measured slope of 0.0026 ft per L.F.(.26%), as determined using the "Clay Pipe Engineering Manual," published by the National Clay Pipe Institute, is approximately 1.1 MGD (4070 M^3/D).



JOB NO. 79-2012
VIDEO TAPE NO. TAPE #1 SEC 4
OPERATOR AL GERBER
TELEVISION INSPECTION REPORT (FIELD COPY)
DATE: 5 / 8 / 79
TIME: 10:00 A.M.
INSITUFORM RELINING NORTHBROOK
FROM MANHOLE "A" NUMBER: 2
LOCATION: LAWTER CHEM.NORTH DR.
TO MANHOLE "B" NUMBER 3
LOCATION: 990 SKOKIE SOUTH DR.
ST. LOCATION SKOKIE HWY PK WAY

STORM ☐ SANITARY ☒
SIZE 8 10 12 15 18
CONST.CODE VCP
MEAS. DIST. 150 FT.
SPACING 60 IN.
VID.TAPE.REF.START 40 FIN

Manhole Reference No. "A" Condition Summary:
Location Code PK WAY
Depth in Feet 9.2
Const. Code BR PC BL
Rpr. Recommend. Code NONE

Flow 0.0

Flow 0.0

Manhole Reference No. "B"
Location Code PK WAY
Depth in Feet 10.0
Const. Code PR-CAST
Rpr. Recommend Code NONE
Pipe Condition G F [✓ P]
Rpr. Recommend. Code LIN
Line Location: PK-WAY
Remarks:
LINE PLUGGED DURING INTERNAL INSPECTION.

			CONDITION																									
			LINE									JOINT						SERVICE										
Ref. No.	Footage	Clk. Ref.	Obstruction	Dirty Line	Broken Pipe	Radial Cracks	Lat. Cracks	Multi Cracks	Infiltration	In Sag	Out Sag	Infilt. Dep.	Offset	Pulled	Roots Light	Roots Med.	Roots Heavy	Wye	Tap	Size	Inactive	Running	Projection	Infiltration	Service Roots	Infil GPM	Ph.Vid. Ref.	Remarks
1	26	2:00																	x	4		x	x	x		.2		Small Flow
2	116	2:00																	x	4		x	x	x		.2		Large Flow
3	144													x												1.0		
4	150																											M.H. "B"
5																												
6																												
7																												
8																												
9																												
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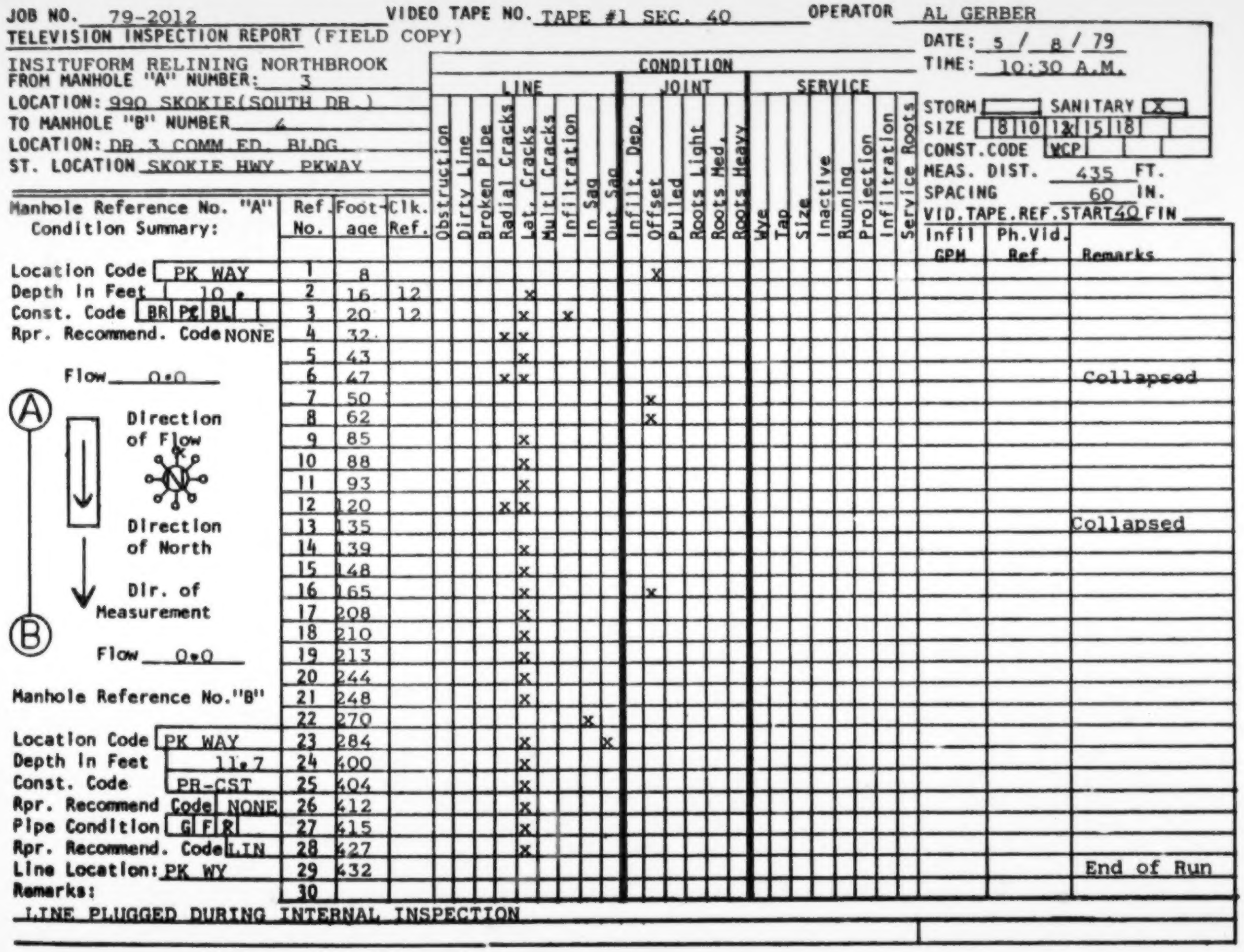
Figure 2. Television Inspection - Log Test Section MH #2 to MH #3



JOB NO. 79-2012 VIDEO TAPE NO. TAPE #1 SEC. 40 OPERATOR AL GERBER

TELEVISION INSPECTION REPORT (FIELD COPY)

DATE: 5 / 8 / 79
TIME: 10:30 A.M.

INSITUFORM RELINING NORTHBROOK
FROM MANHOLE "A" NUMBER: 3
LOCATION: 990 SKOKIE(SOUTH DR.)
TO MANHOLE "B" NUMBER 4
LOCATION: DR.3 COMM ED. BLDG.
ST. LOCATION SKOKIE HWY. PKWAY

STORM ☐ SANITARY ☒
SIZE 8 10 12 ☒ 15 18
CONST. CODE VCP
MEAS. DIST. 435 FT.
SPACING 60 IN.
VID. TAPE. REF. START 40 FIN

Manhole Reference No. "A"
Condition Summary:
Location Code PK WAY
Depth In Feet 10
Const. Code BR [✓ PC] BL
Rpr. Recommend. Code NONE

Flow 0.0

Ⓐ

Direction of Flow

Direction of North

Dir. of Measurement

Ⓑ

Flow 0.0

Manhole Reference No. "B"
Location Code PK WAY
Depth In Feet 11.7
Const. Code PR-CST
Rpr. Recommend Code NONE
Pipe Condition G F [✓ R]
Rpr. Recommend. Code LIN
Line Location: PK WY
Remarks:
LINE PLUGGED DURING INTERNAL INSPECTION

			CONDITION																									
			LINE									JOINT						SERVICE										
Ref. No.	Footage	Clk. Ref.	Obstruction	Dirty Line	Broken Pipe	Radial Cracks	Lat. Cracks	Multi Cracks	Infiltration	In Sag	Out Sag	Infilt. Dep.	Offset	Pulled	Roots Light	Roots Med.	Roots Heavy	Wye	Tap	Size	Inactive	Running	Projection	Infiltration	Service Roots	Infil GPM	Ph.Vid. Ref.	Remarks
1	8												x															
2	16	12					x																					
3	20	12					x		x																			
4	32					x	x																					
5	43						x																					
6	47					x	x																					Collapsed
7	50												x															
8	62												x															
9	85						x																					
10	88						x																					
11	93						x																					
12	120					x	x																					
13	135																											Collapsed
14	139						x																					
15	148						x																					
16	165						x						x															
17	208						x																					
18	210						x																					
19	213						x																					
20	244						x																					
21	248						x																					
22	270									x																		
23	284						x				x																	
24	400						x																					
25	404						x																					
26	412						x																					
27	415						x																					
28	427						x																					
29	432																											End of Run
30																												

Figure 3. Television Inspection - Log Test Section MH #3 to MH #4

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This theoretical capacity is based upon the following assumptions:

1. Sewage is considered to have same flow characteristics as water.
2. The sewer is assumed to have uniform flow conditions.
3. The sewer is classified in hydraulic terminology as an open channel.
4. The slope and cross-section of the line is constant throughout.
5. The roughness of the line is constant throughout and the line is assumed to have a roughness coefficient of 0.013.

The actual capacity of the test sections are reduced somewhat due to isolated inconsistencies, such as root intrusions, offset joints, broken pipe, invert deposits, alignment variations, etc. Results from the limited number of measurements were scattered. Therefore, the actual Manning "n" was assumed to be 0.014, giving a section capacity of 1.0 MGD (3800 M^3/day).

FLOW DATA

In an effort to obtain typical hydraulic loadings of the test section NB instruments, Model GR portable flow meters were installed in the upstream (MH 2) and downstream (MH 4) manholes for a period of two weeks prior to liner insertion, and then reinstalled for a period of two weeks after the rehabilitation was performed (see Figure 4). Each meter was continuous reading and recording on a seven-day strip chart. The depth readings from the strip charts were converted into flow quantities using Mannings Equation (detailed on page 25, after physically field determining the flow cross-section and slopes of each line. Daily Average Flows (DAF) and Peak Daily Flows (PDF), along with daily contributions from sewer users tributary to the test segments, are presented in Tables 1 and 2 of this report. These Tables indicate the monitoring results both before and after Insituform lining. As can be seen from these Tables the DAF through the test sections ranges between 0.25 (925 M^3/D) and 0.4 MGD (1480 M^3/D) with daily peaks reaching approximately 0.8 MGD (2960 M^3/D). The meter readings at the upstream manhole were taken to be representative of DAF due to the fact that a large watermain leak was detected within the test section during the project. Flows from services within the test segment were monitored on a daily basis over the project period by Village of Northbrook staff.

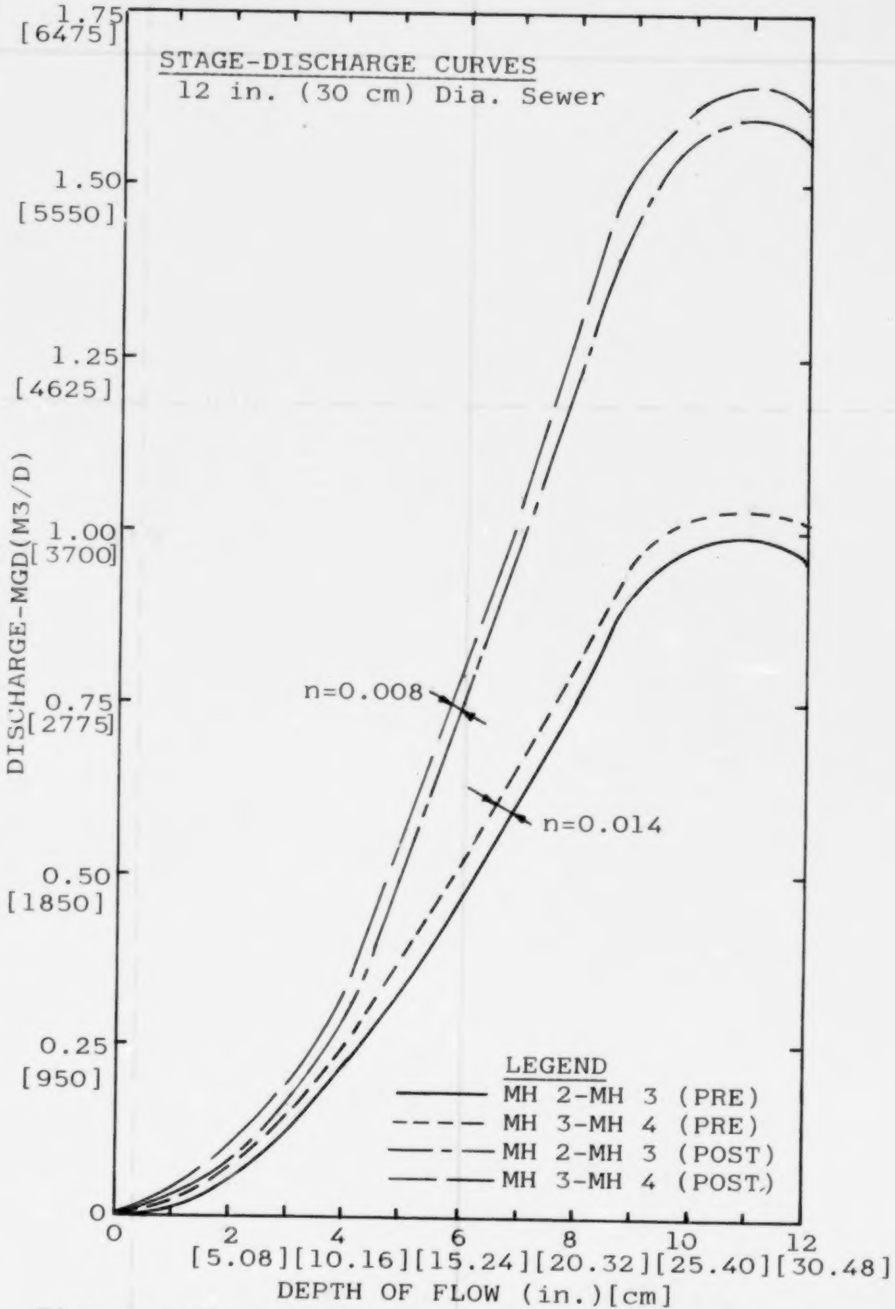

Figure 4 Stage-Discharge Curves for Test Sections

TABLE 1. HYDRAULIC LOADINGS PRIOR TO LINER INSERTION

INSITUFORM STUDY

PRE-INSITUFORM

DATE SEPT. 1979	GAGING STA. - MH 2					GAGING STA. - MH 4					FLOW DIFF. MGD (M³/DAY)	SERVICE FLOW MGD (M³/DAY)	INFILTRATION MGD (M³/DAY)	PEAK FLOW d/D		GROUNDWATER HEAD AT INV (cm)		RAIN FALL (cm)
	d/D	PART. FLOW FACT.	SLOPE %	CAPACITY MGD (M³/DAY)	ACTUAL FLOW MGD **(DAF)** (M³/DAY)	d/D	PART FLOW FACT.	SLOPE %	CAPACITY MGD (M³/DAY)	ACTUAL FLOW MGD **(DAF)** (M³/DAY)				GAGE# MG 2	GAGE# MH 4	GAGE# MH 2	GAGE# MH 4	
17	.42	.3779	.253	.990(3663)	.3741(1384)	.57	.6213	.27	1.0244(3790)	.6365(2355)	.2624(970			.43	.62			0
18	.44	.3779	.253	.990(3663)	.4010(1483)	.55	.5750	.27	1.0244(3790)	.5890(2179)	.1880(695			.47	.61	50	111	0
19	.44	.4050	.253	.990(3663)	.4010(1483)	.55	.5750	.27	1.0244(3790)	.5890(2179)	.1880(695			.50	.62	52	168	0
20	.44	.4050	.253	.990(3663)	.4010(1483)	.54	.5640	.27	1.0244(3790)	.5778(2137)	.1768(654	.003620(13)	.173180(640)	.44	.60	50	116	0
21	.44	.4050	.253	.990(3663)	.4010(1483)	.52	.5200	.27	1.0244(3790)	.5327(1970)	.1317(487	.001300(4)	.130400(482)	.45	.57	73	113	0
22	.41	.4050	.253	.990(3663)	.3470(1283)	.53	.5480	.27	1.0244(3790)	.5614(2077)	.2144(793			.43	.57			0
23	.40	.3506	.253	.990(3663)	.3203(1185)	.65	.7600	.27	1.0244(3790)	.7785(2880)	.4582(1695			.42	.73			0
24	.42	.3236	.253	.990(3663)	.3741(1384)	.69	.8160	.27	1.0244(3790)	.8359(3092)	.4618(1708	.002110(7)	.459690(1700	.45	.76	70	118	0
25	.40	.3779	.253	.990(3663)	.3203(1185)	.64	.7240	.27	1.0244(3790)	.7417(2744)	.4214(1559	.001100(4)	.420300(1555	.43	.76	65	116	0
26	.40	.3236	.253	.990(3663)	.3203(1185)	.68	.8000	.27	1.0244(3790)	.8195(3032)	.4992(1847	.001570(5)	.497630(1841	.43	.77	65	118	0
27	.38	.3236	.253	.990(3663)	.2961(1095)	.69	.8160	.27	1.0244(3790)	.8359(3012)	.5398(1997	.001150(4)	.538650(1993	.43	.74	62	113	0
28	.40	.2991	.253	.990(3663)	.3203(1185)	.66	.7690	.27	1.0244(3790)	.7878(2914)	.4675(1729	.001580(5)	.465920(1723	.43	.71	73	118	0
29	.36	.3236	.253	.990(3663)	.2513(929)	.63	.7190	.27	1.0244(3790)	.7365(2725)	.4852(1785			.37	.75			0
30	.36	.2539	.253	.990(3663)	.2513(929)	.64	.7240	.27	1.0244(3790)	.7417(2744)	.4904(1814			.32	.72			0
10-1		.2539	.253	.990(**3663**)		.64	.7240	.27	1.0244(3790)	.7417(2744)					.76			

n = 0.014

NOTE: Infiltration may be inflated due to watermain leak over sewer. **(FLOW DIFFERENTIAL VALUE INDICATES LEAK)**

No inflow sources became apparent during study.

Parentheses ( ) indicate metric quantities.

All groundwater readings taken by Village of Northbrook staff.

DRIVER, OLSON AND DeGRAFF
PROFESSIONAL ENGINEERS AND LAND SURVEYORS
77 SEVENTH STREET
ROCKFORD, ILLINOIS 61104

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TABLE 2. HYDRAULIC LOADINGS AFTER REHABILITATION

POST-INSITUFORM

INSITUFORM STUDY

DATE OCT. 1979	GAGING STA. - MH 2					GAGING STA. - MH 4					FLOW DIFF. MGD ✱ (M³/DAY)	SERVICE FLOW MGDx10⁻³ (M³/DAY)	INFILTRATION MGD (M³/DAY)	PEAK FLOW d/D		GROUNDWATER HEAD AT INV (cm)		RAIN FALL (cm)
	d/D	PART. FLOW FACT.	SLOPE %	CAPACITY MGD (M³ DAY)	ACTUAL FLOW MGD (DAF) (M³ DAY)	d/D	PART. FLOW FACT.	SLOPE %	CAPACITY MGD (M³/DAY)	ACTUAL FLOW MGD (DAF) (M³/DAY)				GAGE# MH 2	GAGE# MH 4	GAGE# MH 2	GAGE# MH 4	
9	.30	.185	.253	1.603(5931)	.2966(1097)			.27	1.656(6127)					.34				0
10	.28	.168	.253	1.603(5931)	.2693(996)			.27	1.656(6127)					.38				0
11	.28	.168	.253	1.603(5931)	.2693(996)			.27	1.656(6127)					.71				0
12	.28	.168	.253	1.603(5931)	.2693(996)			.27	1.656(6127)					.38				0
13	.27	.155	.253	1.603(5931)	.2485(919)			.27	1.656(6127)					.38				0
14	.29	.174	.253	1.603(5931)	.2789(1031)			.27	1.656(6127)					.44				0
15	.32	.208	.253	1.603(5931)	.3334(1233)			.27	1.656(6127)					.46				0
16	.32	.208	.253	1.603(5931)	.3334(1233)			.27	1.656(6127)					.46		80	136	0
17	.30	.185	.253	1.603(5931)	.2966(1097)	.38	.288	.27	1.656(6127)	.4769(1764)	.1803(667)	.650(2)	.179650(664)	.41	.59	62	128	0
18	.32	.208	.253	1.603(5931)	.3334(1233)	.38	.288	.27	1.656(6127)	.4769(1764)	.1435(530)	1.07(3)	.14243(526)	.42	.52	57	123	0
19	.34	.235	.253	1.603(5931)	.3767(1393)	.39	.303	.27	1.656(6127)	.5018(1856)	.1251(462)	1.230(4)	.123870(458)	.44	.53	60	121	0.3
20	.34	.235	.253	1.603(5931)	.3767(1393)	.39	.303	.27	1.656(6127)	.5018(1856)	.1251(462)			.39	.51			0
21	.33	.220	.253	1.603(5931)	.3527(1304)	.38	.288	.27	1.656(6127)	.4769(1764)	.1242(459)			.38	.49			0
22	.35	.248	.253	1.603(5931)	.3975(1470)	.34	.235	.27	1.656(6127)	.3892(1440)	.0083(30)	2.130(7)	-.010430(38)	.54	.46	52	126	0
23	.31	.196	.253	1.603(5931)	.3142(1162)	.30	.185	.27	1.656(6127)	.3064(1133)	.0078(28)	1.070(3)	-.008870(32)	.49	.52	50	151	0
24	.28	.168	.253	1.603(5931)	.2693(996)	.32	.208	.27	1.656(6127)	.3444(1274)	.0751(277)	1.740(6)	.073360(271)	.49	.54	52	141	0
25	.27	.155	.253	1.603(5931)	.2485(919)	.29	.174	.27	1.656(6127)	.2881(1065)	.0396(136)	1.180(4)	.038420(142)	.46	.52	60	136	0
26	.32	.208	.253	1.603(5931)	.3334(1233)	.28	.168	.27	1.656(6127)	.2782(1029)	.0552(204)	1.420(5)	-.056620(209	.47	.51	57	128	0
27	.30	.185	.253	1.603(5931)	.2966(1097)	.26	.128	.27	1.656(6127)	.2120(784)	.0846(313)			.51	.53			0
28	.26	.128	.253	1.603(5931)	.2052(759)	.30	.185	.27	1.656(6127)	.3064(1133)	.1012(374)			.44	.41			0
29	.38	.288	.253	1.603(5931)	.4617(1708)	.32	.208	.27	1.656(6127)	.3444(1274)	.1173(434)	1.900(7)	-.119200(441	.55	.32	95	126	0
30	.38	.288	.253	1.603(5931)	.4617(1708)	.32	.208	.27	1.656(6127)	.3444(1274)	.1173(434)	1.220(7)	-.118520(438	.50	.32	90	118	0
31	.28	.168	.253	1.603(5931)	.2693(996)			.27	1.656(6127)			1.840(6)		.62		98	121	1.0

n = 0.008

NOTE: Parentheses ( ) indicates metric quantities.
All groundwater readings taken by Village of Northbrook Staff. Apparent erroneous readings may have resulted from plugging of perforations.

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ROCKFORD, ILLINOIS 61104

✱ MOST LIKELY DUE TO MANHOLE INFILTRATION.

Previous to lining, significant wet weather precipitated flows which initiated surcharging, thereby indicating flows in excess of 1.0 MGD (3800 M^3/D). Intermittent problems with the meters prohibited truly accurate flow data, but did give an indication of the effectiveness of the technique in reducing infiltration within the test section. Investigations of the meters revealed at times that the arms on the units would periodically stick, and that debris would occasionally hang up on the float, thus creating erroneous readings.

Daily flow metering of the test section prior to rehabilitation indicated infiltration within the test section varying from 0.17 MGD (629 M^3/D) to 0.54 MGD (1998 M^3/D). These values are very large for an I/I contribution on a segment of this length. They can be chiefly attributed to a large watermain leak previously mentioned flowing almost unrestricted into the sewer. Also, the accuracy of the flow metering devices is a factor. There were no inflow sources detected within the test sections. So that before-and-after infiltration tests might be more meaningful, the Village officials agreed not to repair the watermain leak until after all flow monitoring was completed.

Flow metering data compiled under ground water, time, flow and weather conditions similar to before lining showed infiltration after sewer lining with Insituform to range from 0.18 MGD (666 M^3/D) to a negative value of -0.12 MGD (-444 M^3/D). The accuracy of the flow metering devices makes these relative differences highly questionable. However, the data in Tables 1 and 2 indicates a reduction in clear water flow. The detailed I/I tests performed manually at the site directly before and after the rehabilitation program are much more representative of the actual effectiveness of the technique.

GROUND WATER CONDITION

To relate the interdependence between infiltration and relative ground water elevation in the study areas, daily records were kept by Village forces of the ground water depths during the same period that flow monitoring was in progress.

Ground water gauges were installed at the extremities of the test section, two at MH 2 and two at MH 4. The purpose of installing two ground water gauges at each extremity was to determine the well-point effect that occurs in the ground water table when a trench backfilled with relatively permeable material acts as the means to conduct ground water into a perforated conduit (badly disjointed and broken pipe) in which it is carried away with the wastewater. Theoretically the further from the trench that the ground water is measured, the shallower should be the reading; thereby, evidencing a movement of ground water toward the trench (Figure 5). To bear out this theory one ground water gauge was placed in the manhole, with a corresponding unit placed some 15 ft (4.6 m) from the manhole measured perpendicular to the trench line. Data collected (Table 3) indicated that indeed the well-point-draw down phenomena does occur in this situation even though granular bedding was not used in the installation of the main and in-place material was apparently used as backfill. In some cases the elevation of the ground water surface at the manhole was more than 2 ft (61 cm) lower than that 15 ft (4.6 m) remote. This condition can be attributed to the reduced compaction of the backfill material coupled with the restratification of the in-place material during backfill operation.

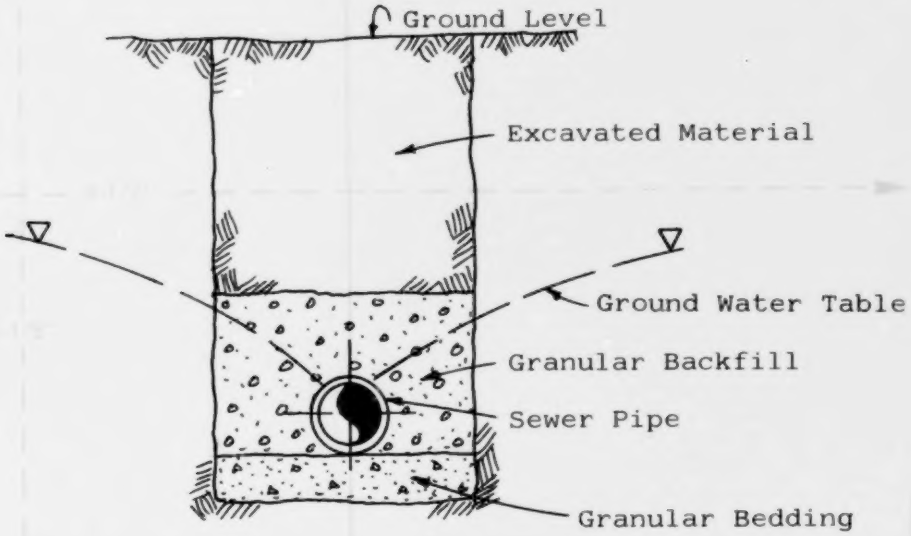
Ground Level
Excavated Material
Ground Water Table
Granular Backfill
Sewer Pipe
Granular Bedding

Figure 5. Trench Drawdown Effect

Typically during the period of flow data collection, the ground water was over the crown of the sewer by 1 ft (.3 m) at MH 2 and 2.5 ft (.75 m) at the downstream manhole. This information is presented in Tables 1 and 2, but the level does not fluctuate to the extent that its effect upon the infiltration in the test section would be a meaningful relationship; therefore, a graph of this relationship is not included.

Table 3. TRENCH DRAWDOWN EFFECT

DATE 1979	GROUND WATER ELEV. IN MANHOLE NO. 2	GROUND WATER ELEV. REMOTE	DIFF. IN GROUND WATER ELEV.	GROUND WATER ELEV. IN MANHOLE NO. 4	GROUND WATER ELEV. REMOTE	DIFF. IN GROUND WATER ELEV.
9-18	88.24	90.24	2.0	90.10	90.83	0.73
9-22	88.44	90.24	1.8	90.20	91.00	0.73
9-24	89.31	90.91	1.6	90.20	91.08	0.88
9-26	89.04	90.74	1.7	90.10	91.08	0.98
9-28	88.55	90.65	2.1	90.20	91.08	0.88
10-16	88.84	91.24	2.4	91.06	91.66	0.60
10-18	88.89	90.49	1.6	90.50	91.25	0.75
10-22	88.92	90.32	1.4	90.50	91.33	0.83
10-24	88.92	90.32	1.4	90.60	91.83	1.23
10-26	89.09	90.49	1.4	90.65	91.41	0.76

All measurements are in ft. To convert to m multiply by 0.305.

INFILTRATION

In an effort to determine the effectiveness of the Insituform technique upon infiltration sources, the following methods of study were implemented, taking note that due to conditions that prevailed, different approaches were used in each test section.

On the upstream test section from MH 2 to MH 3, the upstream manhole was plugged and a 90 degree V-notch weir installed in the downstream manhole, also service taps in the stretch were plugged and the flow bypassed downstream. After the flow over the weir stabilized, flow measurements were taken at seven-minute intervals with the average pre-lining infiltration being approximately 19,500 gallons daily (74 M^3/D) (Table 4). The ground water at MH 2 during this analysis was some 13 in. (33 cm) over the crown of the outlet pipe, this being much lower than during testing periods shown in Tables 1 and 2. This data would seem to be more reliable than that monitored and recorded prior to and after the demonstration due to the total section isolation; note that the infiltration value shown here is only for the sewer between MH 2 and MH 3, and that shown in Tables 1 and 2 is for the entire section. As previously stated, the vast majority of the measured clear water in this segment was due to a watermain leak near MH 3. Because of the limited time (some two hours) which was available from the initiation of the bypass operation until the insertion of the Insituform liner, it was not possible to establish a functional relationship between the amount of rainfall, ground water depth and clear water flow in the sewer.

TABLE 4. WEIR ANALYSIS OF INFILTRATION

STRETCH MH2 - MH3

PRE-LINING (OCT. 2, 1979)		POST-LINING (OCT. 4, 1979)	
TIME	INFILTRATION BY WEIR GPD(M^3/D)	TIME	INFILTRATION BY WEIR GPD(M^3/D)
9:53 a.m.	36,000(137)	2:24 a.m.	
10:00 a.m.	25,500(97)	2:52 a.m.	Flow was not measurable-- 100(.38)
10:07 a.m.	19,500(74)	2:59 a.m.	
10:15 a.m.	19,500(74)	3:07 a.m.	
10:20 a.m.	19,500(74)	3:15 a.m.	
Ground water above crown	1.08 ft(.32m)	1.20 ft(.36m)	

After this test section was lined and just prior to the discontinuation of bypass pumping, similar procedures to those described in the previous paragraph were used in developing a post-Insituform value of infiltration within the section. Barely a trickle was noted over the weir during the second battery of tests, with the clear water contribution estimated at less than 100 GPD. Since the service connections had not yet been cut and reconnected to the main, it was deduced that the infiltration noted was coming from seepage through the walls, bench, and pipe entrance and exit areas of MH 2.

Test section 2, downstream of that described in the previous paragraph and between MH 3 and MH 4, was tested by means of exfiltration tests. The reasoning behind the performance of this type of test was that a badly damaged storm sewer in this area was drawing the water table down significantly. Efforts to obtain records or plans of this storm sewer proved fruitless. Attempts to artificially increase the elevation of the water table by sprinkling failed. Therefore the section between MH 3 and MH 4 was filled with water by plugging the downstream manhole as well as MH 3 and filling the section from a fire hydrant while normal flow was being overpumped. By measuring the decrease in the water level over time in MH 3, it was determined that the pre-lining value for exfiltration was approximately 3800 GPD (14.06 M^3/D)(Table 5).

TABLE 5. ANALYSIS OF EXFILTRATION

STRETCH MH 3--MH 4					
PRE-LINING (OCT. 2, 1979)			POST-LINING (OCT. 4, 1979)		
Time	Water Level in MH 3 above crown ft(m)	Exfiltration Rate GPD(M^3/D)	Time	Water Level in MH 3 above crown ft(m)	Exfiltration Rate* GPD(M^3/D)
11:05 a.m.	3.00(.90)		3:35 a.m.	3.00(.90)	
11:20 a.m.	2.50(.75)		3:50 a.m.	3.00(.90)	
11:35 a.m.	2.15(.65)	3900(14.4)	4:05 a.m.	2.93(.88)	
11:40 a.m.	Refill MH		4:20 a.m.	2:90(.87)	
11:45 a.m.	3.00(.90)		4:35 a.m.	2.88(.86)	274(1.01)
11:55 a.m.	2.60(.78)				
12:10 p.m.	2.33(.70)	3643(13.5)			
Ground water	Not Measurable			Not Measurable	

*Most likely leaking through manhole structure.

Post-lining studies, of an identical nature, showed that exfiltration reduced significantly to approximately 270 GPD; most of this exfiltration probably occurred within the manholes.

Studies conducted after the Insituform was cured uncovered several visible artesian leaks within the manholes displaying the migration of ground water along the main line to these structures. It would be prudent, therefore, to include coincident with Insituform sewer lining rehabilitation of defective manholes, if possible.

FLOW CHARACTERISTICS

As part of this study, flow characteristics of the sewer prior to and after lining were determined; Manning's Roughness Coefficient (n) was calculated initially for the deteriorated test sections, and then recalculated after the sections were rehabilitated to establish the improved smoothness of the bore. The testing procedure utilized the Manning Equation as defined below:

$$Q = A \frac{1.486}{n} S^{1/2} R^{2/3}, \text{ Where}$$

Q represents the rate of discharge measured in cubic feet per second, a known quantity in this test.

A is the area of the wetted cross-section of the pipe measured in square feet, a measured quantity in this case.

n is a coefficient which is used as a measure of the interior surface roughness of a pipe, known as Manning Roughness Coefficient, and was determined by this analysis.

S represents the slope of the energy gradient of the line, which in this case was assumed to be the same as the slope of the conduit measured in feet of drop per running foot of pipe. Parameters to determine this were measured in the field.

R is the hydraulic radius of the wetted cross-section of pipe, arrived at by dividing the wetted cross-sectional area of the flow by the wetted perimeter of the pipe.

Detailed analysis of the before-and-after flow properties of the lines were not performed during this study; such determinations are to be more exhaustively analyzed under a future program. For the purposes of comparison of "n", the following method was implemented to give representative values for the parameter.

Prior to and after lining the test sections, the sewage flow was bypassed around the segments. Known quantities of water from the public water system varying in discharge from 110 to 280 GPM (.42-1.06 M^3/Min.) were then metered separately by means of a recently-calibrated 2.44 in. (6.2 cm.) hydrant meter into each test section, and the depth of flow measured with a thin stainless steel scale at one-minute intervals in the downstream manhole. The flow introduced into each segment was increased half way through the test to determine the effect on the roughness coefficient "n". The results obtained from the Flow Properties test are displayed in Table 6. Reduction of the raw field data resulted in the following values for roughness coefficient of each test section both before and after lining:

TABLE 6. MANNING ROUGHNESS COEFFICIENT

Pre-Lining Stretch	Slope %	Test Flow GPM(M^3/Min.)	Average Flow Depth in.(cm.)	Calculated "n"
M.H.2-M.H.3	.253	180(.68)	3.0(7.62)	0.0070
		250(.95)	3.5(8.89)	0.0066
M.H.3-M.H.4	.270	110(.42)	3.38(8.85)	0.0162
		200(.75)	3.88(9.85)	0.1026
Post-Lining Stretch				
M.H.2-M.H.3	.253	160(.61)	2.88(7.32)	0.0077
		280(1.06)	3.94(10.00)	0.0079
M.H.3-M.H.4	.270	100(.38)	2.38(6.05)	0.0088
		280(1.06)	3.75(9.53)	0.0081

The pre-lining values obtained for "n" in this analysis appear very suspect. It is believed that the reduced value is due to significant additional flow contributed to the M.H. 2 - M.H. 3 segment through a pulled pipe joint located directly under a watermain break (which was discovered later in the project). Therefore for comparison, pre-lining roughness for the in-place vitrified clay pipe is assumed to be "n" = 0.014. The post-lining "n" is seen to be consistently 0.008-0.009, reflecting a notably smoother condition. Post-lining measurements of the internal diameter of the rehabilitated conduit revealed it to be 11.30 in. (28.70 cm), compared with 11.626 in. (29.53 cm) prior to lining; the in-place liner thickness then is slightly less than 3/16 in. (.41 cm). The reduced cross-sectional area of the sewer coupled with the added smoothness increases the capacity of the test section from 1.1 MGD (pre-lined) to 1.6 MGD (post-lined), or some 48 percent. This increased capacity is corroborated by statements from Village of Northbrook personnel referencing the absence of any surcharging events since the rehabilitation took place. This extremely beneficial quality of the liner can be anticipated down to and including 8 in. (20 cm) diameter sewers; thus, allowing the insertion of a single-layer liner bag in an overloaded sewer strictly for the purposes of increasing hydraulic capacity.

INSTALLATION OF INSITUFORM LINER

Bypass Requirements

Prior to actual installation of the Insituform liner, provisions must be made to overpump the upstream flow around the segment. The actual bypassing setup is of great importance to the success of the lining operation and requires proper planning to assure its adequacy. When planning the overpumping care must be taken so that placement of plugs, suction line, discharge line and pumps does not interfere with the inversion of the liner.

Considerations to be taken in the planning of the bypassing operation include the size of the existing manholes as well as the size and length of the sewer being lined and its wet weather daily average and peak flows. Larger diameter sewers require larger diameter inversion tubes in the inversion manhole, and thus available space for workmen, discharge lines, and suction lines become critical. In many cases it is advisable to bypass from one manhole upstream of the inversion manhole to one manhole past the end of the section being lined. Bypass pumping should be scheduled for twenty-four hours continuous duty from the start of the operation, with back-up equipment available for periods of maintenance and refueling. The actual length of overpumping will depend on factors such as length and size of line, number of services, normal flow in the line, the physical location of the section, and the relative ease with which the operation proceeds.

In most cases, the bypassing of services would not be required as it was in this research project. The reason for this is that, unlike the demonstration, the installation of the liner is generally made at night during periods of limited sewer use by the customers. The user is informed well in advance of the installation date that his water service will be turned off for up to twelve hours. Minimal usage of water should not be allowed since this wastewater tends to collect on the outside of the liner at the service tap, and during cutting operations to reconnect the service this water and debris splashes on the camera lens, signficantly impairing the view and slowing the reconnection procedure.

If the service cannot be limited or turned off for this amount of time, then bypassing of the service will be required. In many cases this can be accomplished by constructing a small sump between the building and the sewer. The downstream side of the sump is plugged and a pump with appropriate hose is installed. The discharge point for the flow from the sewer service would normally be the same as that for the sewer line being bypassed, unless some provision can be made for an intermediate connection.

A very sophisticated bypassing system was developed for the test section in Northbrook. It had been determined in advance of the actual Insituform installation that because of the tests to be run before and after the installation, and the number of spectators involved, that the bypass should be operated for a period of several days.

With this in mind, a bypassing system was set up using 6 in. (15 cm) diameter ABS rigid pipe with the joints solvent welded. The pipe was installed some 20 ft (6 m) west of the existing sewer, and anchored in place on the surface by rebars driven on either side of the pipe. The pipe was then wired to the rebars. Three driveways (which had to remain open) were crossed with overpumping pipe, so that it was necessary to provide crushed stone ramps over the pipe in these locations and maintain these crossings for one week. The bypassing system is shown in Figure 6.

The two services were handled by the construction of sumps on the 6 in. (15 cm) service lines and the installation of one 2 in. (5 cm) diameter electric submersible pump and one portable gasoline power pump. The discharge from the pumps was directly connected to the 6 in. (15 cm) diameter rigid bypass line by means of a solvent-weld wye and necessary bushings. One of the service bypass systems is shown in Figure 7.

Sewer services can be handled by bypass, plugging or limiting discharge. The hydrostatic pressure caused by the presence of waste in the sewer system must never be allowed to be greater than the inversion head.

The total bypass line extended over 1000 ft (305 m) in length starting from one manhole upstream of the two proposed lining sections to one manhole downstream. The original plan called for discharge of the overpumping flow to be at the end of the lining sections, but this discharge caused turbulence which interfered with ongoing tests.

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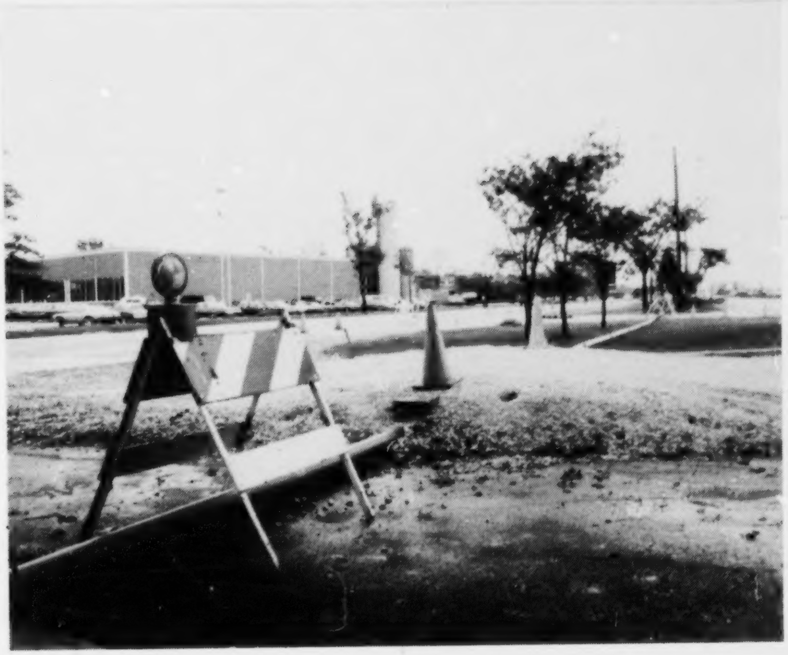

Figure 6. Six-Inch Diameter ABS Rigid Pipe Bypassing System

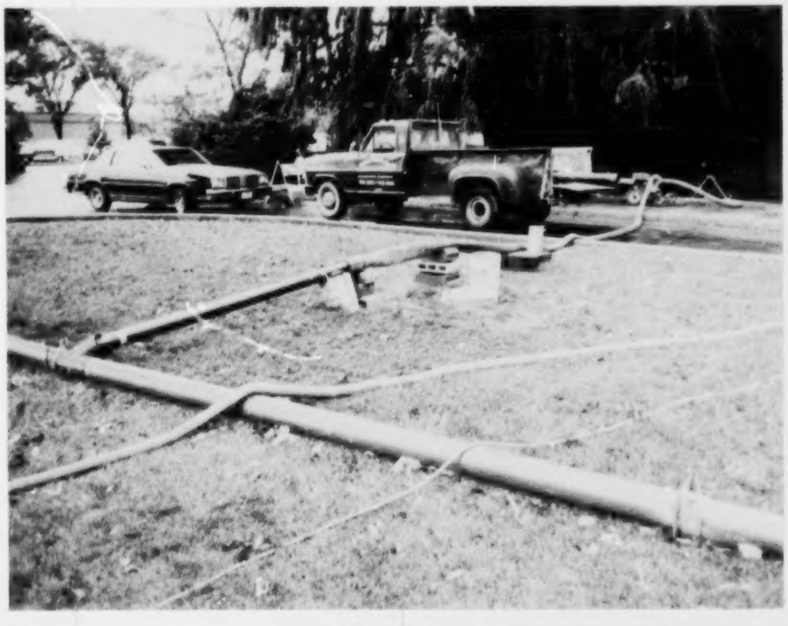

Figure 7. Service bypass sytem with portable gasoline power pump.

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Preparatory Cleaning and Internal Inspection

Preparatory cleaning and internal inspection were also performed just prior to the installation of the Insituform liner. This phase is essential as the Insituform liner bag is inverted into the line and not simply pulled into place. This inversion process causes the bag to unfold from within meaning there is no relative movement between the surfaces of the bag and the pipe being lined after they make initial contact. This lack of movement between the liner bag and the pipe wall results in encapsulation of any material deposits which remain in the sewer during inversion. In addition to the loss in cross-sectional areas due to the encapsulated materials there is also a severe loss of structural strength. A flat area in the bag equivalent to one-quarter the diameter caused by a pipe not being properly cleaned can reduce the structural load carrying capacity by 40 percent; thus, the requirement for preparatory cleaning and internal inspection just prior to installation of the Insituform liner. Additionally, the television inspection will detect any protrusions within the conduit due to poor service taps, broken pipe, etc., which might act to puncture the liner rendering it impossible to cure.

Installation Equipment and Materials

The basic items of equipment and material required for a typical Insituform installation and a brief description of each is as follows:

The inversion platform consists of construction-type sectional scaffolding erected over the point of inversion. The inversion platform supports the inversion tube, workmen, liner bag, and recirculation hose during the inversion phase of the installation. The height of the platform depends on the required inversion head and depth of sewer to be lined. The inversion head requirement will be discussed in more detail in the section on liner insertion, later in this report.

The inversion tube consists of a reinforced polyester tube of sufficient diameter and length to allow the liner bag to pass from the top of the inversion platform to a steel inversion shoe located in the invert of the sewer to be lined. The top of the inversion tube is attached to a steel ring. This steel ring supports the inversion tube which hangs from the inversion platform on cross-members of the scaffolding.

The inversion shoe is a prefabricated 90 degree steel elbow of the appropriate diameter for the sewer being lined and the inversion tube being used. The inversion shoe is attached to the bottom end of the inversion tube by stainless steel straps. The Insituform liner bag is attached to the other end of the inversion shoe also by stainless steel straps. The method of attaching the liner bag will be discussed in detail later in this report.

The portable mixer is a drum type mixer used to mix the appropriate catalyst with the non-promoted resin just prior to transferring the resin from the shipping barrels into the Insituform liner bag.

A transfer pump is the pump used to transfer the catalyzed resin from the shipping barrels into the liner bag for complete impregnation of the felt.

The vacuum pump is a pump used to evacuate the air from the Insituform liner bag prior to introducing the resin into the bag. It enhances the drawing of the resin into the felt. The requirement for a partial vacuum within the bag during this process emphasizes the need for a polyurethane bag-covering which is entirely free of pinholes.

The wet down conveyor system is a three-level conveyor system through which the Insituform liner and resin are passed to insure even distribution of the resin material throughout the entire bag length. Doctor or squeeze rollers are used at the top end of the conveyor to insure the proper resin saturation of the bag material throughout.

The lay-flat hose is a high-pressure hose used to circulate hot water to the far end of the liner bag during the curing process. It must be able to withstand the very high temperature at which the water is being recirculated.

The hold back rope is a rope used to control the rate of inversion after the bag is half way inverted. If the liner inverts too swiftly, the water head may be lost in the inversion tube creating air pockets in the liner. The rope is attached to the end of the bag away from the point of inversion by means of tape and wire. It is also used to help hold back the far end of the bag when it arrives at the desired end of the inversion run.

The water supply line is the line used to supply the water to the inversion tube. In most situations this hose is connected to a nearby fire hydrant.

The water control valve is a valve located at the top of the inversion platform. It is used to control the height of the inversion head and thereby the rate of inversion. It is extremely important that the inversion head be maintained at a static level throughout inversion.

The circulating pump is a pump used to circulate the water from the inversion tube to the heat exchanger and then through the lay-flat hose to the far end of the sewer section being relined.

The boiler and heat exchanger is the source of heat used for bringing the water used in the inversion process up to the curing temperature of the thermosetting resin.

The Insitucutter is a patented device which allows the remote reinstating of existing services by means of a cutter which is pulled through the relined sewer in tandem with an internal inspection camera. The device is positioned and controlled by an operator utilizing a three-dimensional control system to cut out lining material in the areas identified as service taps from the picture on a television monitor. The television monitor shows a picture received from the internal inspection camera which is located on a sled.

Thermocouples are temperature sensing devices placed between the liner material and the sewer wall to read the temperature during the cure and post-cure periods. They give accurate indications of the cure-status of the material.

The liner bag is made from polyurethane-coated, polyester-fiber felt. It is made of densely needled polyester fiber, and can vary in thickness from 1/8 to 3/4 in. (3 to 18 mm) in the prelining state. The liner is usually made of multiple layers of fiber of 1/8 in. (3 mm) each to give the desired total thickness. The primary function of the felt is to act as a medium to hold the resin prior to curing. Each layer is individually sewn into a long cylindrical tube of the proper length and diameter for the proposed lining application. Liners can be custom-designed and constructed for perfect fit. A polyurethane film is applied to the outer surface of the outer layer of material only. Its purpose is to provide an air-tight membrane to enable a vacuum to be drawn on the bag during resin impregnation and to allow the circulation of curing water throughout the liner as well as providing a smooth flow surface for the inverting process.

The polyester resin is a thermosetting resin used to impregnate the polyester fiber felt liner. This material forms the actual smooth, resistant structure within the original conduit. The resin is of the isophthalic-acid-based-polyester thermosetting type and is shipped to the job site non-catalyzed. The resin may contain certain additives to obtain special characteristics required for each application.

A catalyst is the chemical compound such as percadox which is added to the resin to initiate the reactive properties of the resin, to assist in determining the curing temperature, life and hardness of the product. After the catalyst is added to the resin, the resin is considered to be in the promoted, or reactive state.

Installation Procedure

The Insituform installation team consisted of thirteen (13) men as follows: One general foreman, one 3-man preparatory cleaning crew, one 2-man crew for internal inspection and evaluation, one 4-man crew to install and cure the liner and one 3-man crew to cut or reinstate the service laterals.

In addition the Insituform installation team is assisted by a 3-man crew located at the wet out area. This 3-man crew can serve up to three installation teams.

The general foreman is responsible for coordinating the entire installation from initial preparatory cleaning to final inspection and clean up. The foreman may assign additional manpower as required to keep work on schedule.

The 3-man preparatory cleaning crew performs all necessary efforts to prepare the sewer for lining. This may require root removal, bucketing, swabbing or high pressure jetting.

After the preparatory cleaning is completed the 2-man internal inspection and evaluation team makes an inspection of the line to ascertain that the cleaning is complete and also to record on a TV log the location of all line deficiencies and service connections. In addition to the TV log the line is video taped.

As soon as the internal inspection crew completes their work and evaluates that the line is ready for lining the 4-man installation crew starts erecting the inversion platform. This crew is responsible for the actual inversion and curing of the liner as detailed on the following pages.

After the liner is installed, cured and cooled down the services are reinstated by a 3-man crew using the Insitucutter. This crew also performs a post-Insituform internal inspection including the video taping of the Insituformed liner.

The Insituform installation team is supported with the following equipment: sewer cleaning equipment, i.e. high pressure water jet, bucket machines, a twenty-six foot truck equipped with boiler/heat exchanger and circulating pump, a twenty-six foot materials truck and an internal inspection van.

The wet out crew is equipped with a semitrailer truck containing a three tiered conveyor system and appurtenances for mixing and transferring the resin to the liner bag for felt saturation. In addition to the semitrailer truck the wet out crew has tarps used to make sun shades so that all resin handling can be performed out of direct sunlight.

If the pre-Insituform internal inspection indicates the sewer is sufficiently clean and free of protruding services the actual lining procedure can begin.

One of the first steps in the Insituform lining technique is the erection of the inversion platform. This platform is erected over the point of inversion of the liner into the sewer usually a manhole.

The platform is constructed of structural steel tubing using standard scaffold frames and accessories. The scaffold height varies with the depth below grade and the diameter of the sewer being lined as well as the thickness of the liner. The inversion heads may vary from a maximum of 38 ft (11.5 m) on a 6 mm thick, 8 in. (20 cm) diameter bag to as little as 12 ft (3.6 m) on a 9 mm thick 24 in. (60 cm) diameter bag. The larger the diameter, the smaller the head needed for the inversion. Five to six ft (1.5 m - 1.8 m) below the top of the scaffold, a walk platform is installed for the workmen to stand on during the inversion. Eighteen in. (46 cm) below the top of the scaffolding an adjustable inversion tube support system is installed. This support system sustains the steel rings at the top of the inversion tube. At the very top of the scaffold a capstan is positioned to act as a pulley for the bag line or hold back rope.

Care must be taken when erecting the inversion platform to assure the feet of the scaffold legs are on good firm ground and that the scaffold is level in all directions. Some minimal excavation or footing construction may be necessary to provide the desired degree of safety.

At the same time the inversion platform is being erected, the liner bag is being prepared for insertion. There are several steps to be taken in this preparation phase. One of the first and ongoing procedures throughout the entire installation is the visual inspection of the bag for any obvious flaws such as pin-holes or tears in the polyurethane coating. These defects may have been caused in manufacturing the bag, although flaws of this type would have most likely been detected earlier during quality-control by the manufacturer. Faults also may have occurred as a result of shipping or job site handling. If there is a defect in the liner, it is much better to detect it before the liner is installed in the sewer than to realize that the recirculating water is leaking.

After the liner is unpacked from its shipping container, a vaccum pump is attached to the bag to evacuate the entrapped air from the felt-liner material. This, in itself, gives a test as to the soundness of the liner since in a damaged bag, it would be impossible to draw and maintain a vacuum within the system.

While the air is being evacuated from the liner, the resin is being prepared by other workmen. As mentioned earlier, the resin is shipped to the job site unpromoted in drums. The resin is stored in the unpromoted state until just prior to use. It is much more stable and has a longer shelf life in the non-promoted condition.

Resin is generally shipped to the project site in removable lid type drums in order to facilitate mixing and transfer. The lids are removed from the drums and the prescribed amounts of catalysts are added and the ingredients thoroughly mixed with portable flash-type mixers. The lids are then replaced on the drums to await transfer of the resin into the liner bag. Care should be taken to keep the resin material away from direct exposure to sunlight; ultra-violet rays tend to deteriorate the composition of the material. Prolonged exposure in the presence of heat can possibly cause a thermo-setting reaction. The resin may be kept in this state for up to forty-eight (48) hours providing it is out of direct sunlight and below 40°F (4°C).

The quantity of resin used for each installation should be equal by volume to 110 to 115 percent of the volume of felt in the liner bag. Resin material must be liberally-spread throughout the liner bag, replacing all the air in the Insituform. Many times the activated resin contains a dye so that the spread of material throughout the bag can be documented. An air pocket in the liner, devoid of resin will not cure and therefore a soft spot in the finished product will result.

The quantity and type of catalyst are determined based upon the proposed curing conditions as well as the recommendations of the resin manufacturer.

When the desired level of vacuum (5 to 8 pounds per square inch) is reached on the liner bag it is ready to receive the catalyzed or promoted resin. The transfer of resin to the liner is accomplished by the use of a hydraulic transfer pump. The pump suction is placed in each drum and the contents of the drum are pumped to the line opposite the end of the liner to which the vacuum pump is attached. After all the promoted resin has been transferred to the liner, the bag is resealed at the ends.

The next step in the preparation of the liner bag is the saturation of the liner felt. An even and thorough saturation of the liner is very important to assure uniform strength and cure of the line when in place. To assure the even distribution of resin throughout the line it is passed over a three level conveyor system. This variable speed system delivers the liner bag to the squeeze rollers at the proper speed to assure complete saturation of the felt liner. The doctor rolls are preset at the proper thickness to allow just the right amount of resin to pass to assure even distribution throughout the length of the liner. The process of saturating the liner felt with resin is referred to as "Wet Out".

For reasons previously stated, the saturated liner should be kept out of direct sunlight and at or below 40° F (4 °C) during transportation and storage. The "Wet Out" should not occur in excess of twenty-four hours before the estimated installation time.

In most cases the wet down area is located within a few miles of the installation site. However, in the case of Northbrook this was not feasible. Based upon recommendations from Insituform Limited, Northampton, England, Insituform East of Hyattsville, Maryland, was selected to install the test section in Northbrook. After several communications with Insituform East it was determined that it was not practical to transport the entire wet down system over 1600 miles (2575 kilometers) round trip to process the 585 L.F. (175 m) of 12 in. (30 cm) diameter bag needed for the Northbrook project.

An alternative plan was developed to have only the installation crew mobilized from Hyattsville to Northbrook for the liner insertion. After the crew arrived in Northbrook and made their pre-Insituform internal inspection, finding everything in order, they were to alert Insituform headquarters in Hyattsville. The bag would at that time be wet out in Hyattsville and sent non-stop to the project site via refrigerated truck; the trip was estimated to take approximately sixteen hours. All items of the wet out were to be the same as a normal processing procedure.

The Insituform East installation crew arrived in Northbrook, Illinois , Sunday night, September 30, 1979. Early the next morning, the test site was inspected by Insituform East internal investigation personnel, accompanied by the Village of Northbrook Public Works employees along with personnel from the firm of Driver, Olson and DeGraff, Village engineers for this project. During this inspection the overpumping arrangement was reviewed and bypassing requirements were discussed.

The overpumping was started by a local contractor, and initial preparatory cleaning was performed by the Village of Northbrook Public Works Department forces using a high-pressure water jet. Figure 8 shows the cleaning operation. Immediately following the preparatory cleaning, Insituform East personnel performed internal inspection of the line with closed circuit television to verify line condition and length. With this verification completed, the wet down order was relayed to the home office.

Following the internal inspection and with the flow still being bypassed, personnel of the Engineer performed infiltration and flow characteristics tests as previously described in this report. After a final cleaning exercise, the test section would be ready for rehabilitation.

The Village of Northbrook personnel again performed preparatory cleaning to remove gravel that was noted during the previous internal inspection. Again the line was televised to ascertain the results of the latest preparatory cleaning by the Village personnel. The inspection revealed the sewer now to be adequately cleaned so that lining could proceed.

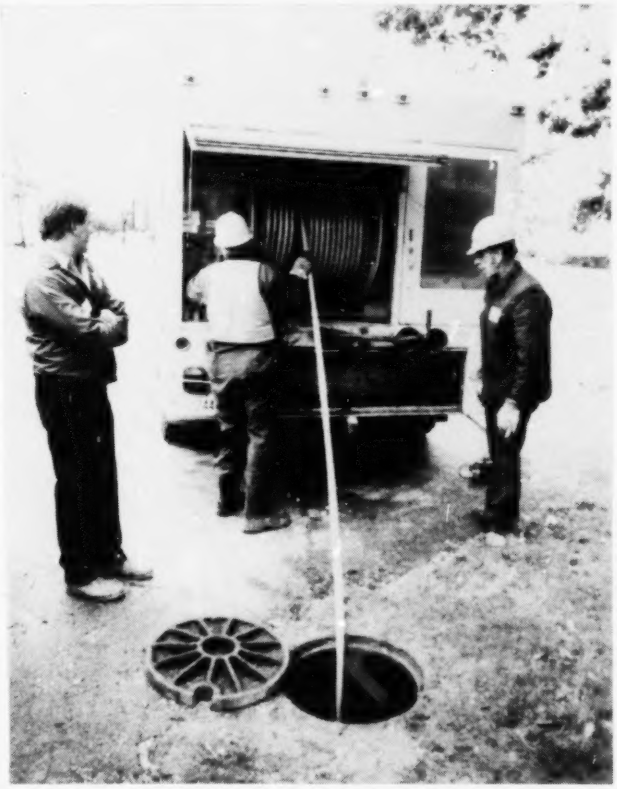

Figure 8. Village of Northbrook Public Works Department performing pre-Insituform cleaning with high-velocity water jet.

Although the actual lining and overpumping equipment was located off the pavement and on the right-of-way, it was decided to block off one lane of traffic of the 4-lane highway. This traffic control was done only for the safety of the observers. It was not actually necessitated by the lining operation. The appropriate signing and traffic control was installed and handled by the Village of Northbrook Public Works Department.

The erection crew began setting up the inversion platform as soon as the cleaning and inspection personnel were clear of the work area. A 20 ft (6 m) static head was to be used to invert the 1/4 in. (6 mm), two-ply, 12 in. (30 cm) diameter liner. The sewer invert at the point of inversion was approximately 9 ft (2.75 m) below ground level and therefore an inversion platform height of 11 ft (3.3 m) was used to give the desired inversion head.

After the scaffolding was erected, the inversion tube support system was installed to anchor the steel rings on the upper end of the inversion tube. Next the inversion tube complete with upper steel ring and inversion shoe was put into position (Figure 9). The lower end of the inversion tube with shoe was carefuly lowered into the manhole to check its position (Figure 10).

The bottom of each leg on the scaffold is equipped with a screw jack to level and adjust the height of the inversion platform. This adjustment permitted the exact positioning of the steel shoe in such a way that the liner bag would report out in line with the sewer. Total length of inversion from start to finish was 585 L.F. (175 m). The installation was made in two separate inversions. The first inversion from Manhole No. 2 to Manhole No. 3 was 150 ft (45 m) in length. The second inversion from Manhole No. 3 to Manhole No. 4 was 435 ft (130 m). Both inversions were made with the flow.

Under normal conditions the entire 585 ft (175 m) stretch between MH 2 and MH 4 would have been inverted at one time with one setup. However, two separate inversions were made in Northbrook to facilitate the large group of observers in attendance. Inversion can be made either with or against the slope of the rehabilitated sewer, but detailed consideration must be given to changes in the grade of the sewer being lined when determining maximum or minimum head that the liner bag will be subject to. Inversion from the middle manhole of the test section could have been planned in Northbrook to eliminate moving and re-erecting the inversion platform, but again two complete inversions were deemed advisable so that spectators not able to attend the first day of inversion would not miss the demonstration entirely.

Water for use in the inversion was supplied by the Village of Northbrook from a hydrant located approximately 120 ft (36 m) south of the inversion platform for Manhole No. 2 and 30 ft (9 m) north of the inversion platform for Manhole No. 3.

A conventional fire hose was used to supply the water from the fire hydrant to the top of the inversion platform. The end of the hose at the top of the inversion platform was equipped with a gate valve to control the

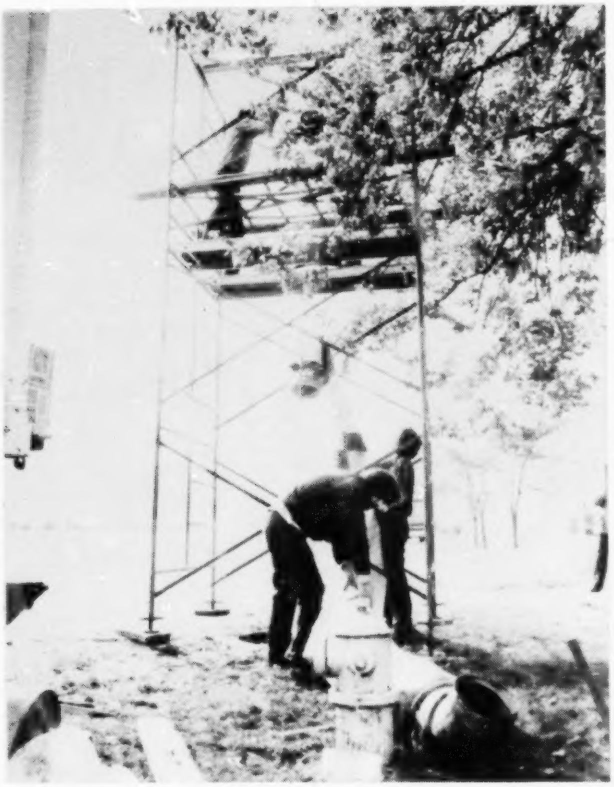

Figure 9. Inversion tube complete with upper steel support ring and inversion shoe being raised into place on the inversion scaffold.

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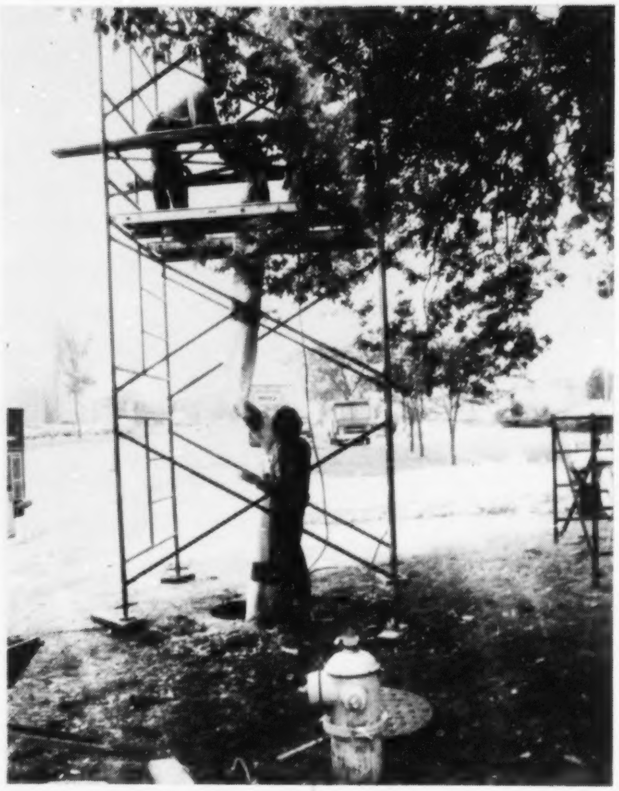

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Figure 10. Inversion tube and shoe being positioned in manhole.

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water supply rate in order to maintain a constant head (Figure 11).

After the inversion platform, inversion tube, and supply hose were in place, the crew was ready for the liner bag. The wetted-out liner bag arrived from Hyattsville, Maryland, in a refrigerated truck, the bag being laid fire hose style in the controlled environment. Upon reaching the site, one end of the bag was immediately cut off and folded over to make a triangular point and taped with duct tape, in order to facilitate passing the bag through the inversion tube. The 12 in. (30 cm) diameter bag is shipped flat and therefore is about 19 in. (48 cm) wide. To pass the liner bag through the inversion tube during insertion it must be folded as it comes off the truck by the installation crew.

Prior to inserting the end of the liner bag into the inversion tube, the portion of inversion tube and inversion shoe previously within the inversion manhole were removed to an above ground position to facilitate the attaching of the liner bag to the inversion shoe. The liner bag end was next passed over a roller conveyor to the top of the inversion platform and down the inversion tube until about 6 in. (15 cm) of the pointed end of the liner bag extended out of the inversion shoe. The liner bag however still was not in position to be attached to the inversion shoe--to clarify, the bag was shipped with the polyurethane coating on the outside and when the liner bag is inverted into the sewer, the polyurethane coating becomes the inside of the liner bag. As the word inversion implies, the liner bag is turned inside out during the installation of the liner (Figure 12). Consequently, the duct tape was removed from the pointed end and the outer layer of polyurethane covered felt was folded back over the inversion tube. Next, a piece of stainless steel banding was tightened over the bag material, firmly attaching it to the inversion shoe (Figure 13). The under layer of felt was then folded back over the shoe and firmly anchored to the shoe--the system used in Northbrook was comprised of two felt layers (Figure 15-1).

The proper banding of the liner bag to the inversion shoe is critical to the work, as should the bag come loose from the shoe or a leak develop at the interface, the inversion would have to be stopped because curing could not proceed. If the problem could not be corrected quickly, the entire insertion might have to be scrapped. This most likely would result in the loss of the liner bag, resin and all preparatory work.

After it was established that the liner bag had been properly attached to the inversion shoe, the inversion tube and inversion shoe were again lowered into position in the manhole for inversion, and wood thrust blocking to brace the shoe was installed (Figure 14 and Figure 15-2).

The water was then turned on, and the inversion tube was slowly filled to the desired inversion head as recommended by the bag supplier (20 ft [6 m] in this case). The bag is restrained until the head is reached by the workmen on the inversion platform and in the truck (Figure 16). The liner bag was then allowed to slowly report out of the inversion shoe and into the sewer itself. As it slowly entered the sewer, a thermocouple was placed between the liner bag and the sewer pipe to measure temperatures in this

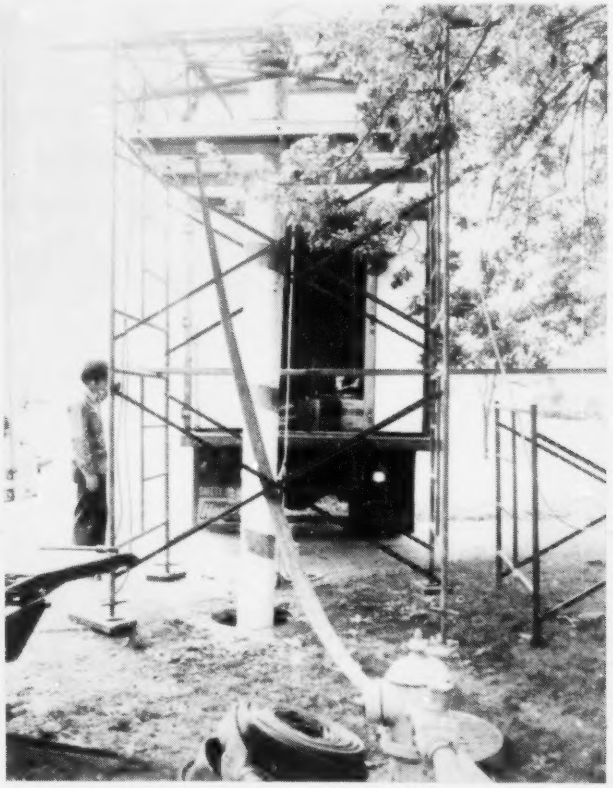

Figure 11. Village of Northbrook hydrant and fire hose used to supply water for the inversion.

Figure 12. Duct taped end of liner bag extending out of inversion elbow.

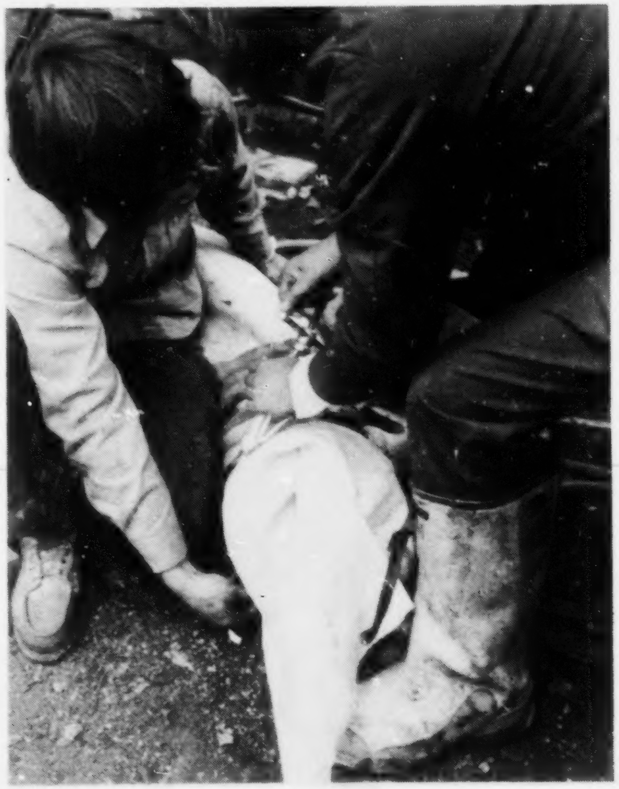

Figure 13. Stainless steel band being tightened on the outer layer or first layer of the liner bag.

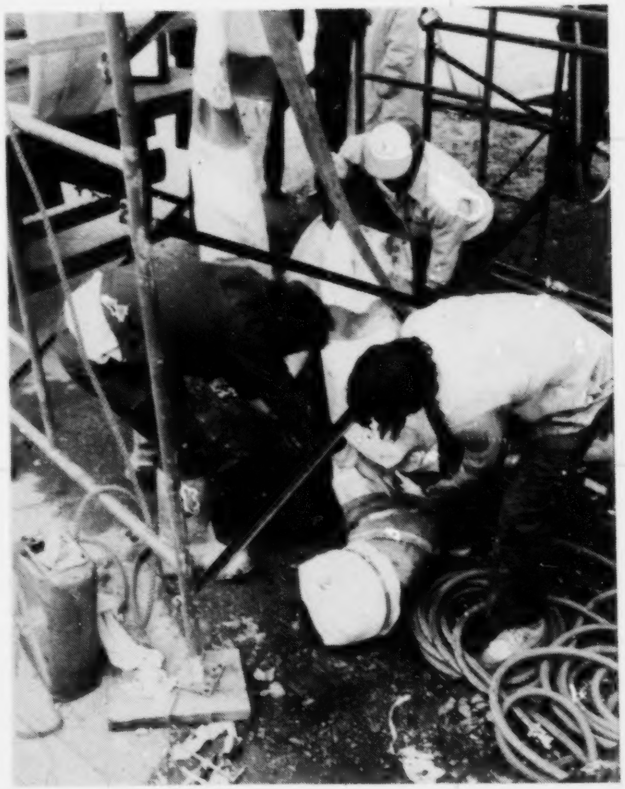

Figure 14. Preparing to lower inversion shoe with properly banded liner bag into inversion manhole.

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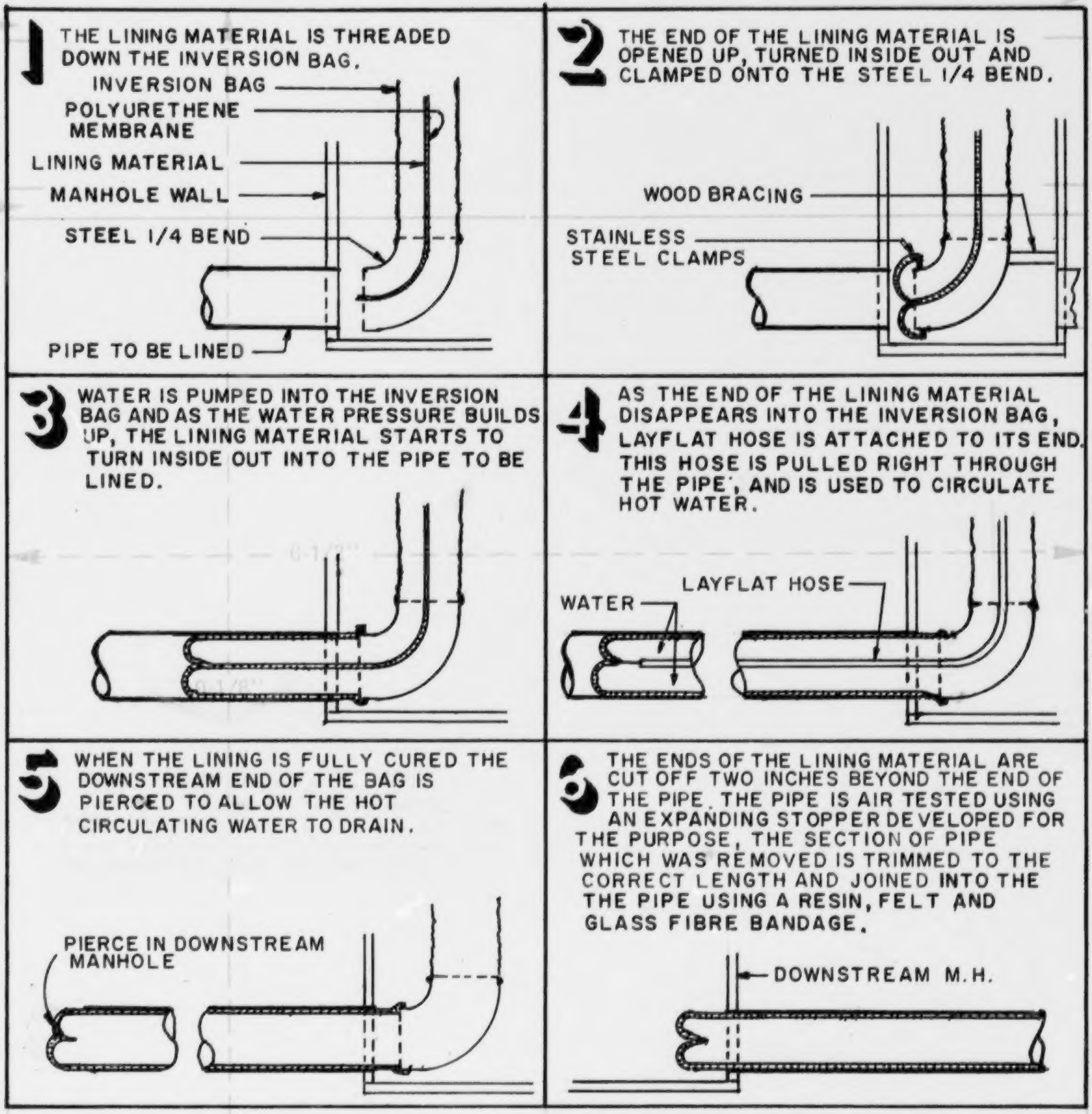

1 THE LINING MATERIAL IS THREADED DOWN THE INVERSION BAG.

2 THE END OF THE LINING MATERIAL IS OPENED UP, TURNED INSIDE OUT AND CLAMPED ONTO THE STEEL 1/4 BEND.

3 WATER IS PUMPED INTO THE INVERSION BAG AND AS THE WATER PRESSURE BUILDS UP, THE LINING MATERIAL STARTS TO TURN INSIDE OUT INTO THE PIPE TO BE LINED.

4 AS THE END OF THE LINING MATERIAL DISAPPEARS INTO THE INVERSION BAG, LAYFLAT HOSE IS ATTACHED TO ITS END. THIS HOSE IS PULLED RIGHT THROUGH THE PIPE, AND IS USED TO CIRCULATE HOT WATER.

5 WHEN THE LINING IS FULLY CURED THE DOWNSTREAM END OF THE BAG IS PIERCED TO ALLOW THE HOT CIRCULATING WATER TO DRAIN.

6 THE ENDS OF THE LINING MATERIAL ARE CUT OFF TWO INCHES BEYOND THE END OF THE PIPE. THE PIPE IS AIR TESTED USING AN EXPANDING STOPPER DEVELOPED FOR THE PURPOSE, THE SECTION OF PIPE WHICH WAS REMOVED IS TRIMMED TO THE CORRECT LENGTH AND JOINED INTO THE THE PIPE USING A RESIN, FELT AND GLASS FIBRE BANDAGE.

INVERSION BAG
POLYURETHENE MEMBRANE
LINING MATERIAL
MANHOLE WALL
STEEL 1/4 BEND
PIPE TO BE LINED
WOOD BRACING
STAINLESS STEEL CLAMPS
WATER
LAYFLAT HOSE
PIERCE IN DOWNSTREAM MANHOLE
DOWNSTREAM M.H.

FIGURE ____: STEPS IN LINING WITH INSITUFORM

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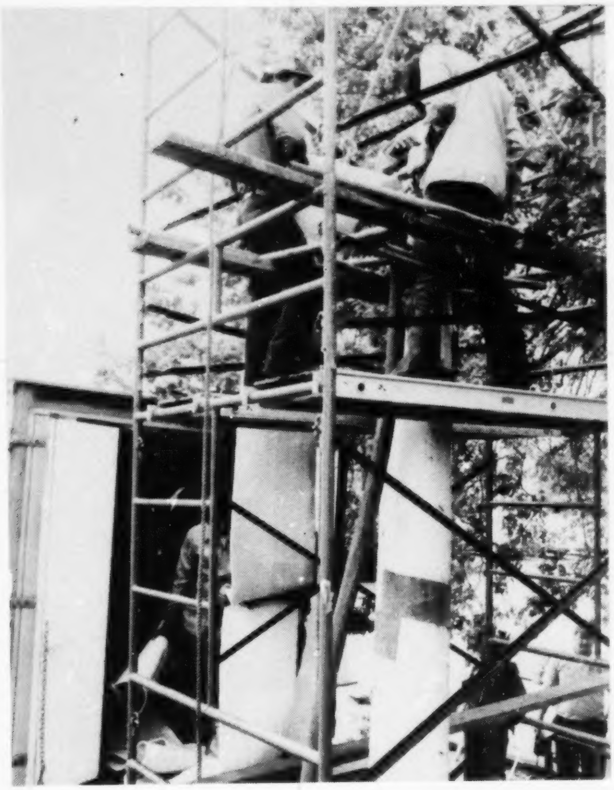

Figure 16. Workman on right turns on water supply valve as workman on left restrains liner bag until inversion head is reached.

critical location (Figure 17); this unit was held in position by static water pressure. Proper alignment of the liner bag into the sewer at the start of the inversion was checked very closely by the installation crew (Figure 15-3).

The supply valve on the water line is carefully controlled to maintain the hydraulic head as the liner was allowed to slowly report out into the sewer. This process continued until the end of the liner bag in the truck was within approximately 10 ft (3 m) of the top of the inversion tube. At this point the inversion was halted. The liner was now half way into the sewer being lined.

A hold back rope was then wrapped around the capstan at the top of the platform and attached to the end of the liner bag. This rope was used to control the rate of inversion by holding back the liner bag. Should the bag be allowed to proceed unimpeded, it would very possibly report out at such a high speed that a constant water head could not be maintained. Simultaneously with the connection of the hold back rope, a lay-flat hose was also attached to the end of the liner bag. The purpose for the lay-flat hose is to carry the heated water from the heat exchanger unit to the far end of the liner bag during the curing process (Figure 18 and Figure 15-4).

It has been found that a more even cure rate can be obtained by allowing a portion of the heated water to be released along the entire length of the lay-flat hose. This is done by providing orifices along the length of the lay-flat hose.

After the lay-flat hose and hold back rope were secured to the bag end, the inversion continued. As the liner bag approached the downstream manhole, a second thermocouple was placed between the liner bag and the sewer pipe wall.

Prior to the inversion process starting, a frame back-stop was installed in the far manhole to assure the stopping position of the liner bag. The liner bag is normally allowed to enter 6-15 in. (15-30 cm) into the far manhole before the inversion is terminated. This projection into the manhole allows the liner bag to expand and cause a slight flared end at the sewer-wall intersection producing a superior seal between the sewer and the liner. After the inversion has been completed, the hold back rope is tied to the capstan at the top of the inversion platform in order to secure the bag in place.

With the liner bag completely inverted, the next procedure was the curing of the thermosetting resin-saturated liner bag. The curing of the liner bag is accomplished by heating the water used to invert the liner bag to a temperature which will cause the resin to cure and harden. The temperature needed to cure the liner bag can be adjusted by the type and amount of catalyst added to the resin before wet-out. In Northbrook the normal cure temperature of 180°F (82°C) was used.

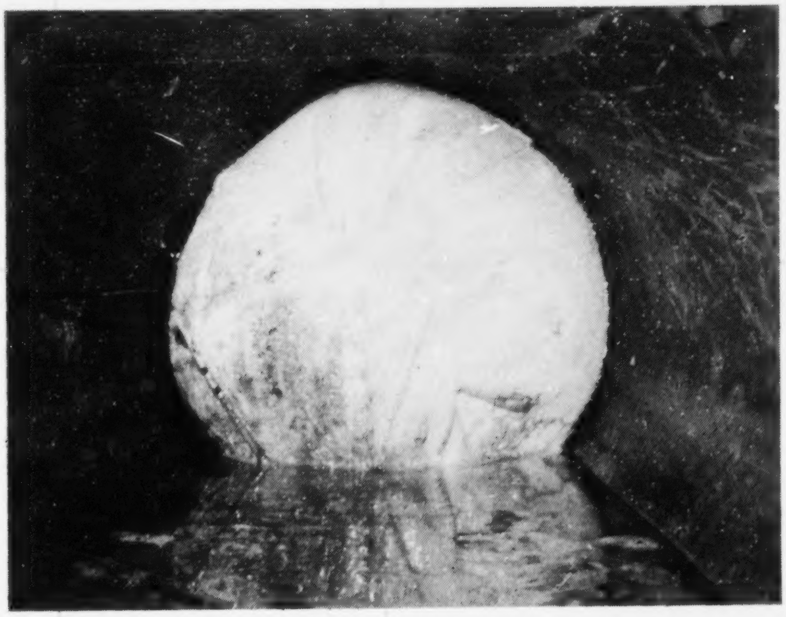

Figure 17. Looking at the liner bag inverting in sewer. At 9 o'clock position, note wires from thermocouple placed in sewer between sewer pipe and liner.

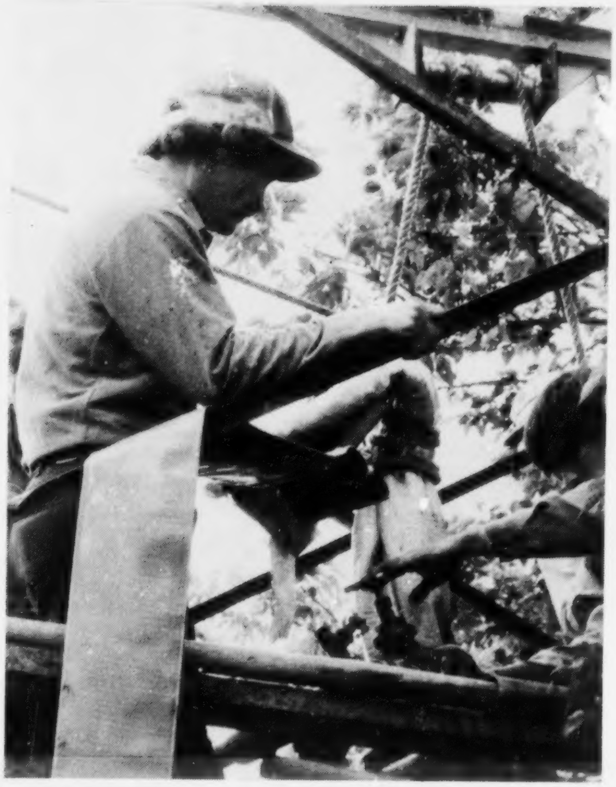

Figure 18. Top right shows rope wrapped around capstan and attached to end of liner bag. Lower left shows lay-flat hose used to circulate heated water from boiler/heat exchanger.

The heat exchanger and recirculation pump were mounted in a truck which was backed up to the inversion platform (Figure 19). This truck also contained a diesel-driven generator to power the electric drive motor on the recirculating pump, and to supply electricity for other lighting and power requirements. In addition to the generator, the truck contained an oil-fired water tube boiler to supply heat for the heat exchanger. A suction line was attached from the inversion tube to the recirculating pump. A second hose attached the heat exchanger to the lay-flat hose. A complete recirculation loop was now in place taking water from the inversion tube through the heat exchanger and returning it back into the sewer line via the lay flat hose.

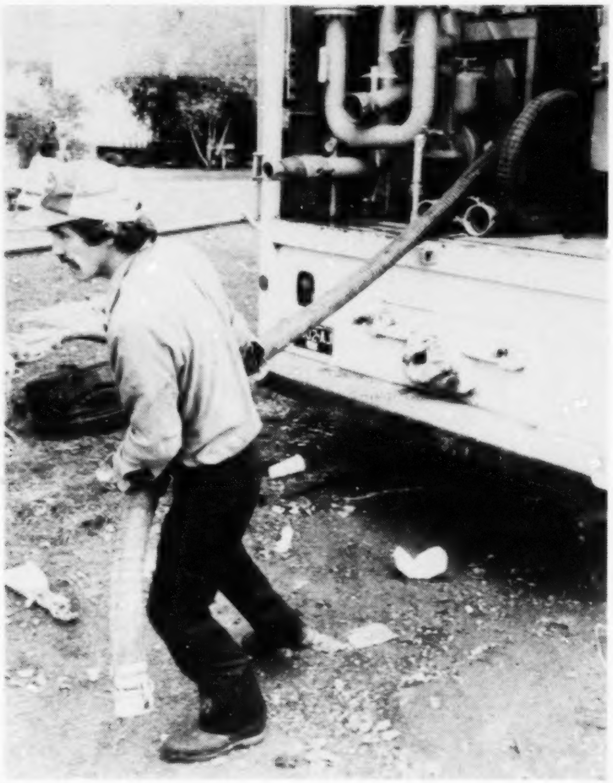

Figure 19. Back of truck showing recirculation pump.

After circulation was begun and it was determined that the flow distribution was proper, the boiler was fired and the heat up began. Water temperature at the beginning of the heat-up was 55°F (12°C). Temperature gauges on the suction and discharge lines in the truck showed that the temperature of the circulated water increased rapidly as it went through the heat exchanger and into the liner section.

Monitoring of the thermocouple temperature at the near and far manholes showed the actual increase in the temperature of the liner bag. The heat sink ability of the ground around a sewer can vary greatly with ground water, backfill and local utility conditions, and therefore the temperature of recirculating water versus liner bag outer surface temperature may vary. Hence, the temperature of the circulating water should never be used as the only criteria for determining the extent to which the process has proceeded.

The curing of the liner in the 150 ft (45 m) inversion from Manhole No. 2 to Manhole No. 3 was as follows. The initial heat up period from 55 F°(13° C) to 160°F (71°C) took 45 minutes. During this portion of the cure the resin went from a liquid to a gel state. The corresponding thermocouple reading was raised to 110°F (43°C). Near the end of the initial heat up period of 45 minutes an exothermic reaction occurred in the resin and the thermocouple reading advanced to 145°F (60°C), sufficient for the liner to harden. The boiler/heat exchanger unit continued to heat the recirculating water from 160°F (71°C) to 185°F (85°C). This operation took approximately an additional 30 minutes while the bag continued to cure. At 185°F (85°C) the bag entered the post-cure period which lasted two hours, the boiler/heat exchanger cycling on and off in order to maintain the 185 °F (85 °C) temperature in the circulating water. A full two hour post-cure insures that the liner will have the highest structural qualities achievable from the particular resin and felt system used. At the end of the post-cure period a hole 1 1/2 in. (3.8 cm) in diameter was pierced in the end of the bag by means of a long steel rod. As the hot water drained slowly out of the bag, cool water was introduced at the inversion tube to maintain the inversion head. The recirculating pumps continued to operate through this cycle. This caused the liner bag to go through a uniform and controlled cool down phase. The cool down period lasted for one hour and reduced the temperature of the circulating water to 100°F (37°C). The controlled cool down period is utilized to prevent thermal shock and to control shrinkage of the polyester material. The total time from heat up to cool down for the 150 L.F. (45 m) section was four hours and fifteen minutes.

The respective times for the inversion from Manhole No. 3 to Manhole No. 4 (435 L.F. [130 m]) were as follows: Initial heat up of 55°F (13°C) to 160°F (71°C) to 185°F (85°C) was 45 minutes; the post cure at 185°F (85° C) was two hours; the cool down period from 185°F (85°C) to 100°F (37°C) was one hour 30 minutes. Total time from heat up to cool down for the 435 L.F. (130 m) section was five hours 30 minutes.

As a safety measure, no one was allowed in any of the manholes downstream of the inversion site while the temperature in the liner was above 100°F (37°C) (Figure 15-5).

When the temperature reached 100°F (37°C) the end of the liner bag away from the inversion manhole was cut open and the inversion water allowed to run out. The ends were then severed at the point of intersection with the manhole walls by using a small diameter, pneumatically-operated, right-angle power saw (Figure 20). Edges of the liner bag were then thoroughly sealed at the manhole wall with a special mixture of resin and sand giving a completed and finished look to the lining, as well as to prevent any migrating clear water from entering the manhole. While the ends of the bag were being cut out and sealed the cleanup crew was dismantling the inversion platform and performing general cleanup (Figure 15-6).

On the second inversion from Manhole No. 3 to Manhole No. 4 the liner was 8 in. (20 cm) short of reporting into the manhole. This did not affect the overall success of the lining installation as there was no damage in the 8 in. (20 cm) between the end of the liner and the manhole. If required the installer was prepared to hand lay a section of liner in the 8 in. (20 cm) non-lined section. This would have been accomplished by using a section of liner bag which was saturated with an epoxy resin capable of curing at the ambient temperature in the manhole.

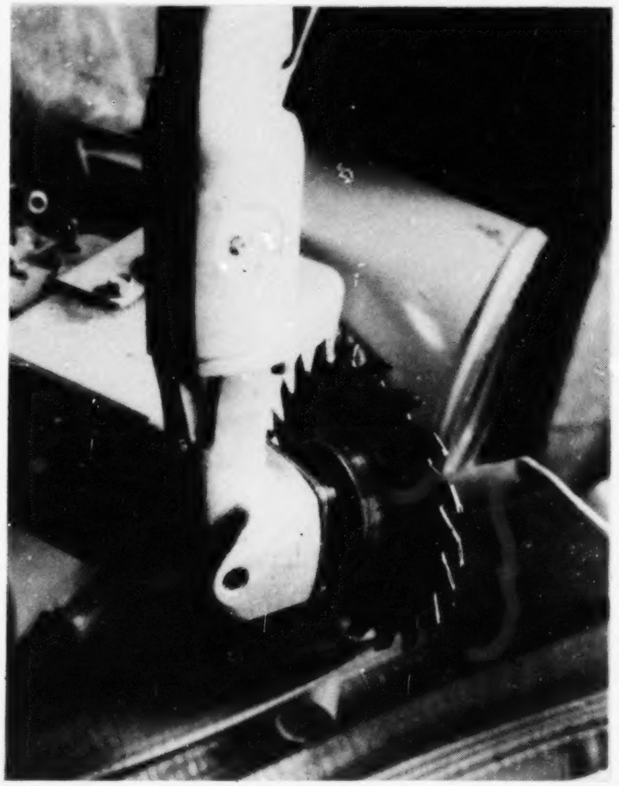

Figure 20. Pneumatically-operated right-angle carbide tip power saw used to cut out ends of liner.

Care should be taken when determining the length of bag required to serve each application. Consideration must be given to the diameter of line, length of line, and the inversion head proposed to be used. The problem associated with a bag that is too short are apparent. The problems with a bag that is too long are not so apparent but are quite real. A bag that is too long means extra cost for wasted bag and resin and extra manpower to remove the uninverted cured portion of the bag. In addition to the above problems, a bag with a long uninverted section prevents the hot water in the lay flat hose from being discharged at the end of the liner bag; thereby, potentially adversely affecting the liner cure.

Special consideration should be given in the future development of the product to safety factors during installation and curing. Care to protect workmen, spectators, and equipment from hot water should be observed by the use of rubber wear and protective shrouds. Any time personnel enter the manholes, self-contained breathing apparatus, helmets, and harnesses must be worn. Strong volatile styrene odors are created during this process, to which prolonged exposure should be avoided.

If installation is made during the night, to take advantage of low sewer flows, the running of equipment such as pumps, boilers, and trucks may cause some problems because of noise in residential areas. This should be evaluated when scheduling installing times and satisfactory arrangements should be made with those involved.

The next step was the reinstatement of the services. This portion of the sewer relining technique is unique to the Insituform procedure. It requires the remote guidance of a cutter, called an Insitucutter, operating within the sewer itself. The Insitucutter is similar to a pneumatic drill or router and is operated in conjunction with the internal inspection camera (Figure 21).

The camera-cutter combination are pulled in tandem through the newly lined sewer in such a way that the camera continually views the cutter. The cutter is located adjacent to the location of each service which has been previously determined and recorded during internal inspections.

In addition to the previously-recorded locations of the services, they may also be detected visually on the interior of the newly-lined pipe; services appear as convex areas on the pipe wall. The operator viewing the service locations positions the Insitucutter by watching a television monitor. He also may place a microphone in the sewer for audio reference, since there is a distinctive difference in the sound levels noted between cutting the liner material and the actual conduit material.

The Insitucutter is capable of movement in six distinct directions. The operator, by both listening and watching the monitor, then proceeds to cut out the liner material covering the service opening. Excess resin in the liner bag migrates into the service joints and forms a seal-like weld between the walls of the service pipe and the liner in the main.

In the Northbrook test sections there were no factory installed wyes or tees present. The two 6 in. (15 cm) service connections in the sewer between Manholes No. 2 and 3 were break-in type connections. Pre-Insituform inspection revealed that the services protruded into the pipe about one in. (2.5 cm). Although it would have been possible to line the sewer without removing these protruding taps, it was decided that they should be corrected because of the physical restrictions to the flow they presented. Each service connection was located, exposed, and the protruding tap removed prior to the lining. The sheeted excavations also provided an excellent point of view for the spectators to see the Insituform reporting into the sewer (Figure 22).

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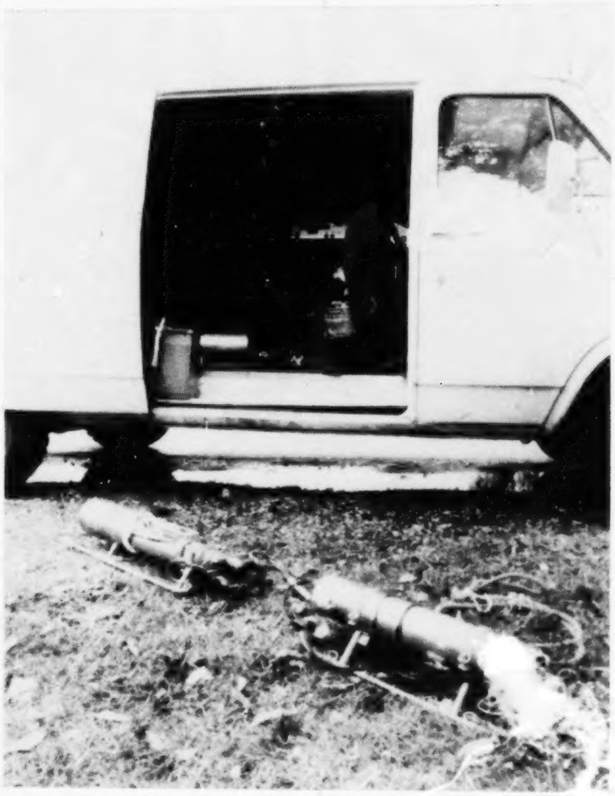

Figure 21. A television camera lower left faces the Insitucutter which is used to remotely reinstate the services. The cutter is controlled by an operator who views the cutting operation from the television van pictures in the background.

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In order to simulate a service renewal, an ABS saddle tee was strapped to the pipe in the area of the old service (Figure 23). The operator then proceeded to remotely open the tap with the Insitucutter (Figure 24). The end results showed the cutting system quite capable of remotely sawing and removing the material covering a service connection. As previously mentioned in this report, problems are created for the service process when water stands in the service behind the liner. When the spinning drill pierces the Insituform covering over the service to be opened, water and liner material are splashed in every direction, including on the lens of the camera; thus, significantly impairing the operators view. Should the debris become heavy, the camera-cutter assembly must be withdrawn from the line for cleaning. This situation can cause a considerable slow-down in the opening of service taps. For this reason, all customers served by the sewer should be notified in advance that water will be shut off prior to rehabilitation. This alone may not totally relieve the situation in that many times infiltration in the service line may backup behind the lining. Service connections should therefore be cut out as soon as is feasible after the liner has cured.

Experience has shown that the average service connection can be renewed by the Insitucutter in approximately 15 minutes. If there are many services to be renewed it is presently the practice to travel the length of the lining and cut a small relief hole in each service dimple. This prohibits a build-up of water from either infiltration or customer use of sanitary facilities. After all service connections have been relieved the Insitucutter then commences to reinstate each service to full bore opening. This procedure in most cases relieves the requirement for providing any alternative sanitary facilities.

Upon completion of the opening of the service connection, a post-Insituform internal inspection was performed. This post-inspection revealed the sewer to be completely relined with a joint-free smooth liner. It was also noted when comparing the pre-Insituform video tapes with the post-Insituform video tapes that in areas of broken pipe that the ceiling subsidence of the broken material had lessened. This occurrence should not be anticipated in every case.

As previously-noted, the rehabilitation performed resulted in the improvement of the pre-lined section in many areas:

1. Manning's Roughness Coefficient of the pipe decreased from 0.014 (assumed) to 0.008-0.009

2. Capacity of the line was increased from 1.0 MGD (pre-lined) to 1.6 (post-lined).

3. Structural integrity and life of the sewer were enhanced.

4. Clear water flow into the line was reduced to a negligible amount.

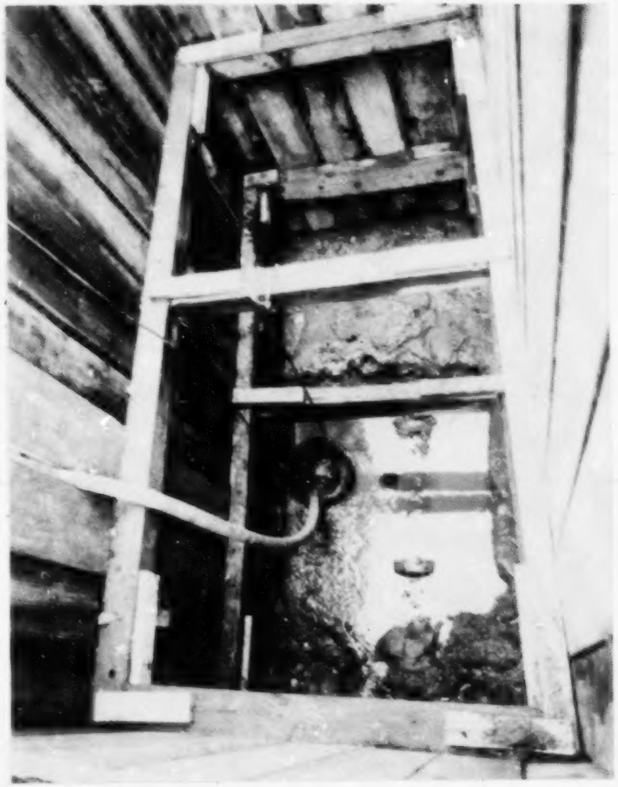

Figure 22. Sheeted excavation at break-in service connection shown after lining was installed and before service was reinstated.

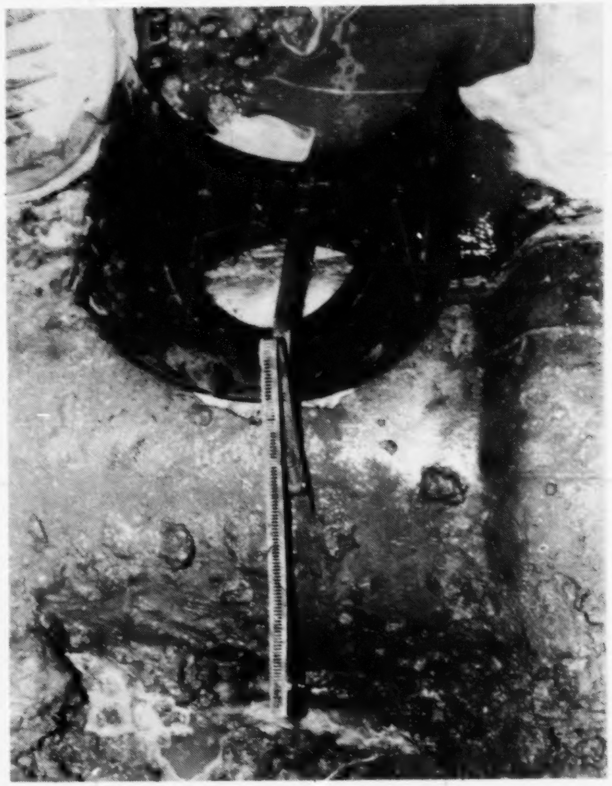

Figure 23. ABS saddle tee strapped upside down to the sewer pipe to simulate service connection.

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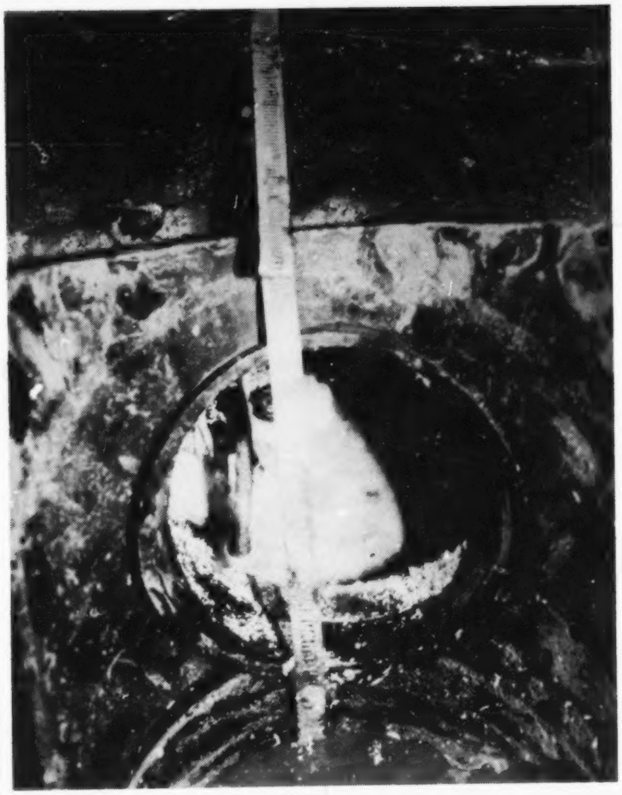

Figure 24. Service connection renewed by the Insitucutter.

PHYSICAL PROPERTIES OF LINER

Initially it was intended to perform an exhaustive battery of destructive physical tests on samples of Insituform which were actually cut from the in-place liner. However, due to the curvature of the samples, laboratories were unable to execute the required analyses per A.S.T.M. standards. For this reason, flat samples of the cured liner material which, by statement from the manufacturer (Appendix A), were of identical materials and thickness and cured in the same manner as the Northbrook test section were made and submitted to an approved, unbiased testing facility. The results received from the laboratory analysis are presented for review as Appendix B of this report. The data indicates the cured liner to be a tough, tenacious material with substantial structural integrity and inertness to chemically-aggressive environments. Although some chemicals reduced the strength properties of the liner, the ultimate values for the parameters after exposure remained acceptable. The product apparently has excellent flexural, shear, and fatigue properties which render it suitable for use in sewer rehabilitation work, where traffic loadings and backfill shifting create common problems. Fatigue tests indicate the cured liner to have properties suitable for the lining of sewers (Table 7).

TABLE 7. TYPICAL MATERIAL PROPERTIES OF CURED INSITUFORM VERSUS PVC (TYPE PSM)

Property	ASTM Test Method	Insituform Liner Northbrook Test Section	PVC
Tensile Strength PSI ($N/m^2 x10^5$)	D-638	5,420 (382)	7,000(394)
Modulus of Elasticity Tension PSI ($N/m^2 x10^5$)	D-638	475,000(33474)	400,000(28889)
Flexural Strength PSI ($N/m^2 x10^5$)	D-790	9,320(656)	11,000(775)
Flexural Modulus PSI ($N/m^2 x10^5$)	D-790	403,000(28400)	-
Compressive Modulus PSI ($N/m^2 x10^5$)	D-695	15,500(1092)	9,000(634)
Coefficient of Thermal Expansion in in/in°C or cm/cm/°C		$5.96x10^{-5}$	$5.2x10^{-5}$
Manning "n" Coefficient of Roughness		.008-.009	.008-.009

Note: Material properties of cured Insituform and PVC can be significantly different than those shown above when different resins are used.

Driver, Olson and DeGraff performed a hydrostatic pressure test on a 5 ft (1.5 m) long section of unsupported lining which was taken from the Northbrook installation. A 12 ft (3.6 m) length of lined vitrified clay pipe between Manhole No. 2 and Manhole No. 3 was excavated and removed. The removed section of pipe was replaced by a section of 12 in. (30 cm) diameter ABS truss pipe. The 12 ft (3.6 m) test section was then taken to Rockford, Illinois, where a 5 ft (1.5 m) section was cut from the 12 ft (3.6 m) length. The test section was then inserted inside a 15 in. (38 cm) diameter asbestos cement pipe. To hold the liner in the center of the asbestos cement pipe and to act as forms for cement bulkheads for each end retainer rings were then glued to the liner and the inside of the asbestos cement pipe with PL200 mastic cement. Steel pins were inserted through the asbestos cement pipe into the retainer rings at approximately 6 in. (15 cm) intervals to reinforce the retainer ring. Before the second retainer ring was inserted, the 2 in. (5 cm) annular space was filled with cement and then the second retainer ring was installed in the same manner as the first. Two 3/8 in. (10 mm) holes were drilled and tapped through the asbestos cement pipe 8 in. (20 cm) from either end. One hole was fitted with a pet cock; the other with an air pressure gauge and filler valve. The end with the pet cock was raised about one in. (2.54 cm) higher than the other end so that as the void area was filled with water through the filler valve air could escape through the open pet cock. When the void was totally filled with water the pet cock was closed and the water filled liner removed. A target was then placed at one end of the pipe and a video camera mounted on a tripod was placed at the other end. The camera and target were so arranged as to allow the camera to view the inside of the liner during the test. Cylindrical rings on the target made it possible for the camera to estimate the liner deformation during the test. Water was used in the void area instead of air to allow visual observation of any leaks as well as to eliminate danger of explosion. An air hose was attached to the filler valve and air pressure was applied until deformation of the liner indicated that deformation of the pipe occured around 50 PSI (3.515 Kg/cm^2). When the pressure was totally released the liner returned to its original cross-section. Visual inspection of the material after testing revealed no apparent cracking which indicates that the liner is a relatively flexible material (see Figure 25 for diagram of test set up).

Since the 12 ft (3.6 m) field specimen that was used for the hydrostatic pressure test included a service connection and joints of the original pipe, visual inspection indicated excellent migration of the resin material into the joints and even into service connection joints, creating an additional seal to infiltration.

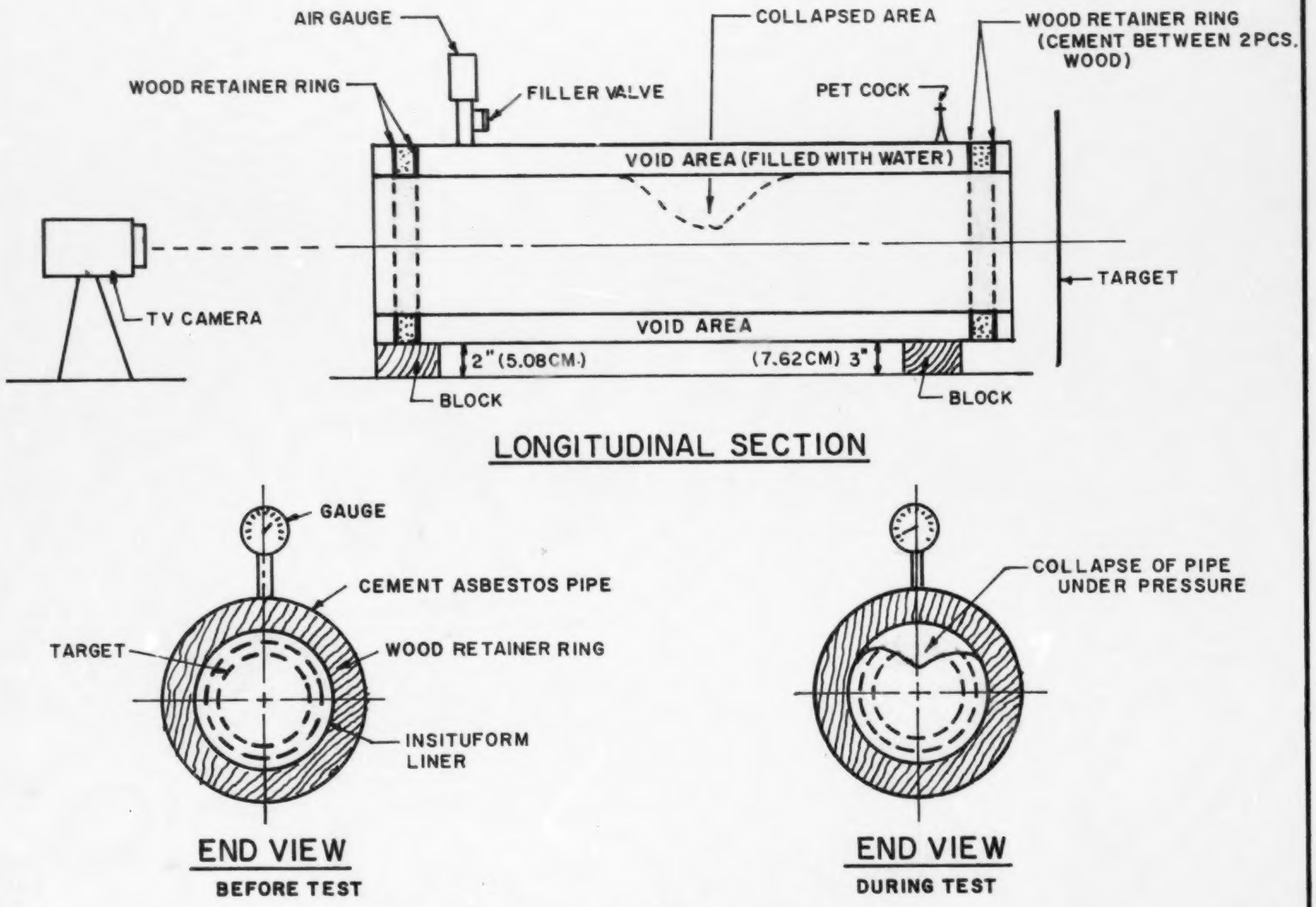
AIR GAUGE
WOOD RETAINER RING
FILLER VALVE
COLLAPSED AREA
PET COCK
WOOD RETAINER RING (CEMENT BETWEEN 2PCS. WOOD)
VOID AREA (FILLED WITH WATER)
VOID AREA
TV CAMERA
TARGET
2" (5.08CM.)
(7.62CM) 3"
BLOCK
BLOCK
LONGITUDINAL SECTION
GAUGE
CEMENT ASBESTOS PIPE
TARGET
WOOD RETAINER RING
INSITUFORM LINER
END VIEW
BEFORE TEST
COLLAPSE OF PIPE UNDER PRESSURE
END VIEW
DURING TEST

Figure 25. Diagram of test set up.

COST EFFECTIVENESS OF INSITUFORM LINER

In this project it was extremely difficult to extablish the cost-effectiveness of the Insituform technique with respect to this application. The main difficulty lies in the prices charged for contracted installation services. Insituform East, backed by the international firm agreed to perform all work necessary to inspect and install the liner for the price of $16,965.30, which was budgeted in the Grant Application and therefore locked in. Ancillary excavation and overpumping functions were handled by the Village of Northbrook. However, the total price for these appurtenant functions was $25,245.41, which far exceeded the insertion cost, and was due mainly to the requirement of a sophisticated bypass system operated over an extended period of time as well as added excavation necessary to expose service connections.

As documented by the site testing done by the Engineer, the total amount of infiltration removed from the sewers in the two test sections was approximately 23,300 gallons (8.8 M^3) daily, or 16.2 gallons (.06 M^3) per minute during a period when the ground water level was relatively low. This data reduces to an actual project cost of $2,605.60 for each gallon per minute of infiltration eliminated. Although this unit cost does not convert into a cost-effective value for this situation, it must be realized that the infiltration in the downstream test section was low during the test period while the overpumping and excavations costs were extremely high.

The Sewer System Evaluation Survey conducted in 1977 concluded that under the then existing high water table condition, the clear water contribution within the two test sections was 67.05 gallons (.25 M^3) per minute. The clear water contribution is typically directly dependent upon the elevation of the ground water table in the area. Typical current prices for rehabilitation with Insituform liners in large-footage situations are shown in Table 8 below.

TABLE 8. INSITUFORM COSTS

Sewer Diameter in.	Liner Thickness mm	Cost per L.F.	Cost per m
6	3	$33.00	$108.27
	6	$39.00	$127.95
8	3	-	-
	6	$42.00	$137.79
	9	$46.00	$150.91
10	3	-	-
	6	$44.50	$146.00
	9	$48.00	$157.48
12	6	$47.00	$154.20
	9	$51.00	$167.32
	12	$55.00	$180.46
15	6	$52.00	$170.60
	9	$57.00	$187.00
	12	$62.00	$203.42

Table 8. (continued)

Sewer Diameter in.	Liner Thickness mm	Cost per L.F.	Cost per m
18	9	$62.00	$203.42
	12	$66.00	$216.53
21	9	-	-
	12	$74.00	$242.78
	15	$80.00	$262.47
24	9	$74.00	$242.78
	12	$80.00	$262.47
	15	$86.00	$282.15

A. Add $1,900.00 per line for overpumping
B. Add $1.90 (6in.-15in.) and $2.50 (15in.-30in.) per foot for preliminary cleaning and inspection.
C. Add an undefined amount for traffic control and mobilization.

Different alternatives of sewer rehabilitation were considered for the Northbrook site. Due to the percentage of failed pipe within the test section specific point repair and grouting were overruled in favor of complete section replacement. A cost estimate for complete section replacement along a parallel path is as follows:

Item	Units	Unit Cost	Total
Sanitary Sewer, 12 in. Dia.	589 L.F.	24.00	14,136.00
Dewatering	589 L.F.	12.00	7,068.00
Manholes	3 each	1,600.00	4,800.00
Services	2 each	400.00	800.00
Granular Backfill	200 C.Y.	10.00	2,000.00
Site Restoration	1 L.S.	17,596.00	17,596.00
Totals -			$46,400.00

Conventional slip-lining was also considered, however, due to the amount of badly-broken pipe and offset joints as well as the capacity problems, it was decided not to be a viable alternative in this situation.

Using the prices in Table 8 and applying them to the Northbrook test site in which 585 L.F. (175m) of sewer was rehabilitated, the anticipated construction cost for the work may be estimated:

1.	Line 585 L.F. (175m) of 12 in. (30.5cm) diameter sewer with 6mm bag @ $47.00/L.F.	$27,448.00
2.	Line preparation	$ 1,111.50
3.	Overpumping	$ 1,900.00
4.	Mobilization	$ 1,500.00
	Total	$31,959.50

This estimate reduces to a construction cost of $54.63 per L.F. of sewer lined. It is shown above and is relatively obvious that in many applications, the unit cost of rehabilitating a deteriorated sewer by the Insituform technique could be much more economical than the replacement or slip-lining alternatives, where factors such as traffic control, service-reconnection, and surface restoration may run the unit costs for these options to over $100.00 per L.F. The test and seal of joints with grouting material generally allows a great cost savings over these three techniques. However it does not lend itself to the rehabilitation of cracked or broken conduit (which was prevalent in this site).

The useful life of the Insituform liner is assumed to be similar to new pipe based on the properties of strength, and resistance to reagents as exhibited in Appendix B. Long-term data from actual installations is unavailable because of the recent development of the method.

Insituform of North American, Inc., Memphis, Tennessee, is presently installing liner bag manufacturing equipment in Memphis. In addition to bag manufacturing Insituform of North America, Inc. will license installers and train all future installers in the United States. Probably as more licensed installers enter the Insituform field, greater competition will result for work, with an accompanying reduction in prices charged.

FOLLOW UP REPORT

Driver, Olson and Degraff inspected the test sections on March 24, 1980, approximately six months after the Insituform installation, in order to determine the effects that time and the elements have had on the Insituform lining. Personnel were dispatched to the site with sewer cleaning and internal inspection equipment. Each test section was thoroughly cleaned and televised, with the results documented on videotape. Comparison of those tapes with those made just after lining was completed indicated there to be no detectable changes in the appearance of the liner over its life. No infiltration was perceived throughout the test stretches in the follow-up tapes. Manholes in the test section were investigated in an attempt to establish whether infiltration had migrated to the manhole joints. No measureable infiltration was noted in the manholes; however, this may be attributable to a ground water table that was relatively low and immeasurable during the inspection.

In an effort to determine what effects an extended period of backfill loading had on the bare liner, a 1 ft^2 (929 cm^2) section of the top of a clay pipe was removed prior to lining and a PVC vertical riser was placed against the Insituform liner and extended to the surface. The elevation of the top of the liner bag was shot prior to backfilling the area and again during the 6-month follow-up study. These measurements indicated the liner to be depressed less than one-eighth of an in. (3mm) at the later inspection, indicating very favorable structural properties of the liner.

The follow-up internal inspection of the test section showed absolutely no build-up of material on the invert of the line, indicating that the flow properties of the section had been significantly improved. The limited follow-up study seems to indicate that the Insituform liner is an effective and durable product for sewer rehabilitation.

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APPENDIX A

INSITUFORM
(PIPES AND STRUCTURES) LIMITED

REGISTERED OFFICE:
HORSLEY ROAD, KINGSTHORPE, NORTHAMPTON, ENGLAND
Telephone (0604) 719606/7/8/9 Telex: 311940 Insitu G
Registered in England No. 996266

Driver-Olson & Associates
6933 Elm Avenue
Rockford, Illinois 61111

Attn: Mr. F. T. Driver, P.E.

Re: Insituform test samples
for Northbrook, Ill.
EPA Project

Dear Mr. Driver:

Pursuant to your request, please be assured that the Insituform samples supplied for testing are representative of the cured liner installed in the 12 inch diameter pipe in Northbrook, Ill.

If I can be of any further assistance, please contact the writer.

Yours sincerely, E. Wood
INSITUFORM (PIPES & STRUCTURES) LIMITED

Eric Wood

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APPENDIX B

United States Testing Company, Inc.
Engineering Services Division
1415 PARK AVENUE • HOBOKEN, NEW JERSEY 07030 • 201-792-2400

REPORT OF TEST

77486
NUMBER

July 9, 1980

CLIENT:
Driver, Olson & Associates
6933 Elm Avenue
Rockford, Illinois 61111

SUBJECT: Physical Properties

REFERENCE:

Driver, Olson & Associates Letter dated 10/15/79

SAMPLE IDENTIFICATION:

One (1) sample of material submitted and identified by the Client as:

Instituform Sewer Material

TESTS PERFORMED:

The submitted sample was tested for the following properties in accordance with the ASTM Test Methods listed below:

	Property	ASTM Test Method
A.	Tensile Properties	D-638
B.	Shear Strength	D-732
C.	Flexural Properties	D-790
D.	Deformation Under Load	D-621
E.	Coeff. of Linear Thermal Expansion	D-696
F.	Deflection Temperature	D-648
G.	Flexural Fatigue	D-671
H.	Compressive Properties	D-695
I.	Bearing Strength	D-953
J.	Resistance to Reagents	D-543

Testing Supervised by:

Frank Razzuoli

SIGNED FOR THE COMPANY

BY Frank Pepe
Assistant Vice President
Engineering Division

Page i of 12
mg

Laboratories in: New York • Chicago • Los Angeles • Houston • Tulsa • Memphis • Reading • Richla

THIS REPORT APPLIES ONLY TO THE STANDARDS OR PROCEDURES IDENTIFIED AND TO THE SAMPLE(S) TESTED. THE TEST RESULTS ARE NOT NECESSARILY INDICATIV REPRESENTATIVE OF THE QUALITIES OF THE LOT FROM WHICH THE SAMPLE WAS TAKEN OR OF APPARENTLY IDENTICAL OR SIMILAR PRODUCTS. NOTHING CONTAIN IN THIS REPORT SHALL MEAN THAT UNITED STATES TESTING COMPANY, INC., CONDUCTS ANY QUALITY CONTROL PROGRAM FOR THE CLIENT TO WHOM THIS TEST PORT IS ISSUED, UNLESS SPECIFICALLY SPECIFIED. OUR REPORTS AND LETTERS ARE FOR THE EXCLUSIVE USE OF THE CLIENT TO WHOM THEY ARE ADDRES AND THEY AND THE NAME OF THE UNITED STATES TESTING COMPANY, INC. OR ITS SEALS OR INSIGNIA, ARE NOT TO BE USED UNDER ANY CIRCUMSTANCES IN AD TISING TO THE GENERAL PUBLIC AND MAY NOT BE USED IN ANY OTHER MANNER WITHOUT OUR PRIOR WRITTEN APPROVAL. SAMPLES NOT DESTROYED IN TES ARE RETAINED A MAXIMUM OF THIRTY DAYS.

Form 806-5/79

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United States Testing Company, Inc.

77486
Number

CLIENT: Driver, Olson & Associates

July 9, 198

TEST RESULTS:

Test and Units	Determined
A. Tensile Properties	
(1) Tensile Strength, psi	5,420
(2) Modulus of Elasticity, psi	475,000
B. Shear Strength, psi	8,150
C. Flexural Properties	
(1) Flexural Strength, psi	9,320
(2) Flexural Modulus, psi	403,000
D. Deformation Under Load, pct. (800 psi, 158°F, 24 Hrs.)	0.149
E. Coefficient of Expansion, in/in/°C	5.96×10^{-5}
F. Deflection Temperature, °C	
(1) @ 66 psi	106
(2) @ 264 psi	92.5
G. Fatigue Endurance Limit, psi @ 10^7 cycles	1360
H. Compressive Properties	
(1) Compressive Strength, psi	15,500
(2) Compressive Modulus, psi	325,000
I. Bearing Strength, psi	
1. @ 4% Deformation	3330
@ Maximum	5910

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Resistance to Reagents

Reagent 168 Hr. Immersion	Tensile Properties Tensile Strength,psi	Tensile Properties Modulus, psi	Compressive Properties Comp. Strength,psi	Compressive Properties Modulus, psi
1. Acetic acid, 70% sol. @ 77^{0}F	5860 (+8%)	435,000	14,300 (-8%)	298,000
2. Ammonia, 5% sol. @ 77^{0}F	4810 (-11%)	465,000	14,800 (-5%)	297,000
3. Brine, 10% sol. @ 122^{0}F	4670)-14%)	474,000	13,300 (-14%)	253,000
4. Calcium Hydroxide 0.18% Sol. @ 95^{0}F	5430 (+0.2%)	460,000	14,300 (-8%)	317,000
5. Diesel Fuel @ 95^{0}F	4300)-21%)	568,000	13,800 (-11%)	250,000
6. Hydrochloric Acid, 35% Sol. @ 77^{0}F	5110 (-6%)	446,000	13,700 (-12%)	271,000
7. Gasoline @ 77^{0}F	5100 (-6%)	457,000	14,800 (-5%)	311,000
8. Nickel Plating, Sol @ 133^{0}F	4720 (-13%)	464,000	11,800 (-24%)	260,000
9. Sulfuric Acid, 15% Sol. @ 86^{0}F	5280)-3%)	471,000	13,900 (-10%)	291,000

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77486
Number

CLIENT: Driver, Olson & Associates

July 9, 198

DATA:

Tensile Properties

Determination	Cross Sectional Area, Sq. In.	Tensile Strength, psi	Modulus of Elasticity x 10^5
		Initial (As Received)	
1	0.133	5270	4.52
2	0.133	5600	4.70
3	0.118	4250	5.15
4	0.134	6050	4.53
5	0.134	5930	4.83
Average		5420	4.75
		After 168 Hrs. in 70% Acetic Acid Solution @ 77°F	
1	0.127	6090	4.26
2	0.133	5350	4.49
3	0.119	6170	4.30
4	0.125	5820	4.10
5	0.122	5840	4.59
Average		5860	4.35
		After 168 Hrs. in 5% Ammonia Solution @ 77°F	
1	0.127	5570	4.68
2	0.124	4110	4.24
3	0.131	4790	4.42
4	0.123	5240	4.79
5	0.133	4340	5.10
Average		4810	4.65
		After 168 Hrs. in 10% Brine Solution @ 122°F	
1	0.120	3990	4.64
2	0.129	5110	4.27
3	0.132	5190	6.06
4	0.132	3740	4.32
5	0.127	5340	4.43
Average		4670	4.74

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Tensile Properties (Cont.)

After 168 Hrs. in 0.18% Calcium Hydroxide Solution @ 95°F

Determination	Cross Sectional Area, Sq. In.	Tensile Strength, psi	Modulus of Elasticity, x 10^5
1	0.128	5390	4.60
2	0.128	5150	4.60
3	0.135	4960	4.55
4	0.129	5750	4.34
5	0.126	5890	4.94
Average		5430	4.60

After 168 Hrs. in Diesel Fuel @ 95°F

Determination	Cross Sectional Area, Sq. In.	Tensile Strength, psi	Modulus of Elasticity, x 10^5
1	0.135	4220	6.15
2	0.128	4180	5.99
3	0.125	4480	4.83
4	0.135	4070	5.49
5	0.134	4560	5.96
Average		4300	5.68

After 168 Hrs. in 35% Hydrochloric Acid Solution @ 77°F

Determination	Cross Sectional Area, Sq. In.	Tensile Strength, psi	Modulus of Elasticity, x 10^5
1	0.133	5160	4.48
2	0.127	4810	4.79
3	0.126	5290	4.24
4	0.134	4780	4.54
5	0.130	5500	4.24
Average		5110	4.46

After 168 Hrs. in Regular Gasoline @ 77°F

Determination	Cross Sectional Area, Sq. In.	Tensile Strength, psi	Modulus of Elasticity, x 10^5
1	0.133	5690	4.70
2	0.121	4630	4.46
3	0.130	5680	4.58
4	0.125	4810	4.66
5	0.133	4670	4.47
Average		5100	4.57

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Tensile Properties (continued)

After 168 Hrs. in Nickel Plating Solution @ 133°F

Determination	Cross Sectional Area, Sq. In.	Tensile Strength, psi	Modulus of Elasticity, x 10^5
1	0.130	5140	4.88
2	0.134	3310	4.47
3	0.121	4840	4.66
4	0.127	5460	4.36
5	0.126	4840	4.81
Average		4720	4.64

After 168 Hrs. in 15% Sulfuric Acid Solution @ 86°F

Determination	Cross Sectional Area, Sq. In.	Tensile Strength, psi	Modulus of Elasticity, x 10^5
1	0.126	4910	5.83
2	0.130	5620	5.03
3	0.127	5160	4.37
4	0.136	5020	4.32
5	0.135	5720	4.02
Average		5280	4.71

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Shear Strength

Determination	Shear Area, Sq. In.	Shear Load, Lbs.	Shear Strength, psi
1	0.766	6300	8220
2	0.747	6320	8460
3	0.763	5980	7840
4	0.760	6260	8240
5	0.763	6100	7990
Average			8160

Flexural Properties

Determination	Dimensions, In.	Span, In.	Flexural Strength, psi	Mod. of Elasticity In Flexure, psi x 10^5
1	0.514 x 0.249	4.00	9790	4.03
2	0.536 x 0.242	4.00	9360	3.97
3	0.503 x 0.249	4.00	8950	3.96
4	0.499 x 0.249	4.00	9150	4.07
5	0.478 x 0.243	4.00	9360	4.09
Average			9320	4.03

Deformation Under Load, 800 psi @ 148°F, 24 Hrs.

Determination	Original Height, In.	Deflection, In.	Deformation, pct.
1	0.5326	0.0006	0.113
2	0.5410	0.0010	0.185
Average			0.149

Coefficient of Linear Thermal Expansion

Determination	Initial Length, In.	Temperature Range, °C	Coeff. of Expansion in/in/°C
1	1.986	-30 to +30	5.75×10^{-5}
2	1.986	-30 to +30	6.17×10^{-5}
Average			5.96×10^{-5}

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Compressive Properties

Determination	Cross Sectional Area, Sq. In.	Compressive Strength, psi	Modulus of Elasticity In Compression, psi x 10^5
		Initial (As Received)	
1	0.147	14,800	3.09
2	0.152	15,900	3.21
3	0.140	15,400	3.40
4	0.170	15,500	3.27
5	0.148	16,000	3.30
Average		15,500	3.25
		After 168 Hrs. in 70% Acetic Acid Solution @ 77°F	
1	0.123	14,700	3.01
2	0.133	14,200	2.96
3	0.136	14,100	3.08
4	0.137	14,300	2.82
5	0.137	14,200	3.03
Average		14,300	2.98
		After 168 Hrs. in 5% Ammonia Solution @ 77°F	
1	0.138	14,700	2.78
2	0.123	14,300	2.85
3	0.146	15,300	3.19
4	0.146	15,100	3.11
5	0.136	14,800	2.94
Average		14,800	2.97
		After 168 Hrs. in 10% Brine Solution @ 122°F	
1	0.134	13,100	2.67
2	0.139	13,400	2.44
3	0.141	13,800	2.56
4	0.138	12,500	2.36
5	0.133	13,500	2.63
Average		13,300	2.53

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
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CLIENT: Driver, Olson & Associates

Number 77486

July 9, 1980

Compressive Properties (Cont)

Determination	Cross Sectional Area, Sq. In.	Compressive Strength, psi	Modulus of Elasticity In Compression psi x 10^5
		After 168 Hrs. in 0.18% Calcium Hydroxide Solution @ 95°F	
1	0.125	14,300	3.12
2	0.137	14,400	3.15
3	0.140	14,400	3.18
4	0.139	14,100	3.19
5	0.141	14,400	3.23
Average		14,300	3.17
		After 168 Hrs. in Diesel Fuel @ 95°F	
1	0.136	13,400	2.33
2	0.138	14,700	2.74
3	0.126	12,900	2.61
4	0.135	13,300	2.57
5	0.143	14,500	2.34
Average		13,800	2.50
		After 168 Hrs. in 35% Hydrochloric Acid Solution @ 77°F	
1	0.138	13,600	2.65
2	0.137	13,800	2.78
3	0.136	13,500	2.69
4	0.139	14,000	2.77
5	0.134	13,700	2.66
Average		13,700	2.71
		After 168 Hrs. in Regular Gasoline @ 77°F	
1	0.139	14,400	2.92
2	0.118	14,700	3.07
3	0.140	15,300	3.16
4	0.140	15,200	3.09
5	0.143	14,500	3.31
Average		14,800	3.11

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United States Testing Company, Inc.

77486
Number
July 9, 1980

CLIENT: Driver, Olson & Associates

Compressive Properties (cont)

After 168 Hrs.in Nickel Plating Solution @ 133°F

Determination	Cross Sectional Area, Sq. In.	Compressive Strength, psi	Modulus of Elasticity In Compression psi x 10^5
1	0.140	13,200	1.96
2	0.141	9,700	2.36
3	0.136	13,300	2.51
4	0.141	12,400	2.96
5	0.136	12,500	3.21
Average		11,800	2.60

After 168 Hrs. in 15% Sulfuric Acid Solution @ 86°F

Determination	Cross Sectional Area, Sq. In.	Compressive Strength, psi	Modulus of Elasticity In Compression psi x 10^5
1	0.129	13,600	2.86
2	0.138	14,300	2.93
3	0.131	13.700	2.95
4	0.139	14.000	2.89
5	0.138	13,900	2.92
Average		13,900	2.91

Bearing Strength

Determination	Thickness, In.	Bearing Hole Dia. In.	Bearing Strength, psi @ 4% Deformation	Bearing Strength, psi Maximum
1	0.274	0.250	4370	5810
2	0.279	0.250	3010	5710
3	0.285	0.250	3440	4780
4	0.337	0.250	2800	7250
5	0.274	0.250	3020	5990
Average			3330	5910

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TEST RESULTS:

Flexural Fatigue

Average Thickness	Stress Level, psi	Cycles to Failure
0.266	2000	26,000
		27,000
	1500	138,000
		193,000
		112,000
	1400	279,000
		345,000
	1350	10,000,000 +
		10,000,000 +

Fatigue Endurance Limit: 1360 psi @ 10^7 cycles

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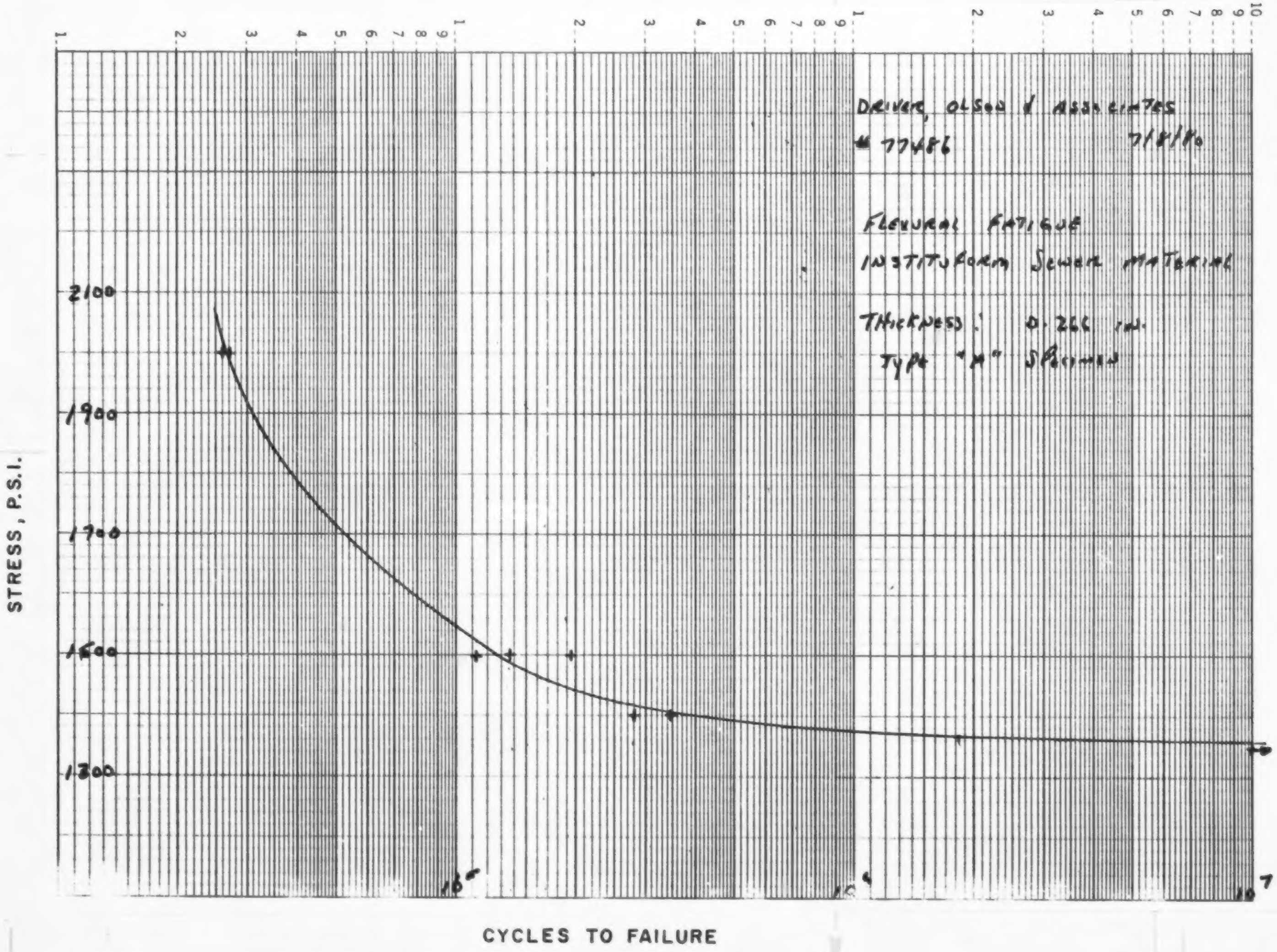

DRIVER, OLSON & ASSOCIATES
77486 7/8/80

FLEXURAL FATIGUE
INSTITUFORM SEWER MATERIAL

THICKNESS: 0.266 in.
TYPE "M" SPECIMEN

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PROJECT # 748
DRAFT # 1060